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USER REQUIREMENTS FOR TERRAIN AND OBSTACLE DATA

RTCA/DO-276
March 5, 2002

Prepared by SC-193

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FOREWORD

This report was prepared by Special Committee 193 (SC-193) and EUROCAE Working Group 44 (WG-44) and approved by the RTCA Program Management Committee (PMC) on March 5, 2002.

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- Coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;
- Analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- Developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- Assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

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EXECUTIVE SUMMARY

This document provides guidance for data gathering by data originators, for data processing by data integrators, for implementation by system designers, and for end use by the aviation community (e.g., air carriers, air traffic services, procedure designers). It is supplemental to the data processing requirements included in EUROCAE ED-76/RTCA DO-200A.

The minimum set of user requirements applicable to terrain and obstacle data, from creation through the entire life cycle, are defined. Numerical requirements for source data necessary to accommodate the most stringent known application requirements are also defined. Collectively these define a set of requirements that satisfy this universal set of applications. It should be noted that the numeric requirements have been derived solely based on user requirements and not on the basis of acquisition cost. Types of errors associated with terrain and obstacles are identified and some means by which these errors may be mitigated are suggested. The integrity, accuracy, and resolution requirements specified in this document and the completeness of resulting databases are not necessarily sufficient for primary means of navigation.

The following four areas of applicability have been defined

the world, the terminal maneuvering area, the CAT II or III Operation Area, and the aerodrome. The requirements for accuracy, integrity and resolution have been tailored to meet these needs.

Guidance for certification or approval of systems or procedures that use terrain and obstacle databases is also provided. It is the responsibility of the applicant to demonstrate that the data meet the requirements for its intended application. The requirements stated in this document address the areas viewed by industry to be of most importance to certification. These areas cover database attributes including accuracy, resolution and integrity. The document also describes the creation and maintenance steps for databases and highlights the certification related verification, validation and traceability requirements in those steps.

The document is organized as follows:

- Section 1 provides background information regarding the purpose for developing terrain and obstacle data requirements.
- Section 2 provides definitions for the terms terrain, obstacle, and significant obstacle which is necessary to distinguish between features in an aviation database.
- Section 3 defines the minimum set of attributes for terrain and obstacle databases.
- Section 4 defines the spatial extent of three areas for obstacles and four areas for terrain and the unique data requirements of each of these areas.
- Section 5 provides guidance related to data quality management.
- Section 6 provides guidance to data suppliers and certification authorities.
- Appendix A is a glossary of relevant terms.
- Appendix B lists important abbreviations and acronyms.
- Appendix C provides an overview of the types of applications which may make use of terrain and obstacle databases.
- Appendix D provides useful information related to data quality assessments.
- Appendix E provides basic information on remote sensing technologies used in the generation of terrain databases.
- Appendix F is a list of references.
- Appendix G lists the membership of the committee that developed this document.

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TABLE OF CONTENTS

APPENDICES

TABLE OF FIGURES

TABLE OF TABLES

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1 PURPOSE AND SCOPE

1.1 Introduction

The document was written to identify requirements for terrain and obstacle data:

- Data originators require the quality characteristics to be defined, including specific numerical values in order to provide data for use in applications. Appendix C provides some illustrative application examples.
- Certification authorities and data users (Cf. Figure 1.1) require information to ensure that terrain and obstacle data satisfy the intended applications.

1.2 Scope

This document defines the minimum user requirements applicable to the origination and publication of terrain and obstacle data from creation through the entire life cycle of the data. Data processing shall be accomplished in accordance with EUROCAE ED-76/RTCA DO-200A. This document provides a minimum list of attributes associated with the terrain and obstacle data and a description of associated errors that may need to be addressed.

The numerical values in Section 4 are defined to accommodate the most stringent known application requirements, and not on a basis of acquisition cost. The integrity, accuracy, and resolution requirements specified in this document and the completeness of resulting databases are not necessarily sufficient for primary means of navigation.

Additionally, guidance material is provided to assist the certification process of an application using terrain and obstacle data.

Land use/land cover database requirements have not been specifically addressed in this document.

1.2.1 Definition of Terms

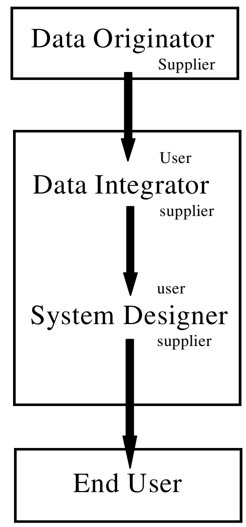
This document contains specific definitions for terrain and obstacles (see section 2.2). A glossary of terms used in this document is provided in Appendix A. A full appreciation of these terms (e.g. resolution, post spacing…) is critical to understanding this document.

1.2.2 Reference Documents

1. ICAO Annex 4, *Aeronautical Charts*
2. ICAO Annex 6, *Operation of Aircraft*
3. ICAO Annex 11, *Air Traffic Services*
4. ICAO Annex 14, *Aerodromes*
5. ICAO Annex 15, *Aeronautical Information Services*
6. ICAO Document 8168, *Procedures for Air Navigation Services, Aircraft Operators*
7. ICAO Document 9157, *Airport Design Manual*
8. ICAO Document 9674, *World Geodetic System 1984, (WGS 84) AN/946*
9. Report of the ICAO Aeronautical Information Services / Aeronautical Charts (AIS/MAP) Divisional Meeting (1998), Montreal, 23 March to 3 April 1998. (Doc 9733)
10. EUROCAE ED-76/RTCA DO-200A *Standards for Processing Aeronautical Data*
11. EUROCAE ED-77/RTCA DO-201A *Standards for Aeronautical Information*
12. EUROCAE ED-99/RTCA DO-272 *User Requirements for Aerodrome Mapping Information*

1.3 Application of This Document

Figure 1.1 describes the data flow that contributes to the design and development of terrain and obstacle databases.



<u>Figure 1-1</u> The Terrain and Obstacle Data Flow

As a first step, each individual State, appropriate delegated agencies or private organisations originate the data. It is beyond the scope of this document to mandate requirements on the originators of such data (derived from topographic survey or satellite imagery...) as it is understood that they already follow clearly identified professional standards, specific requirements and methodologies. Nevertheless, it is recognised that *quality* requirements derived from the system designer or the end user specifications may be equally applicable to the data originator.

Once originated, data may exist in different formats and have different quality characteristics and these data are transmitted to the data integrators, who then merge the data received. The data will then be passed to the system designer for integration into the end-user system.

At each step, the responsibility of ensuring that the data meet requirements for its intended application rests with the user of these data.

1.4 Assumptions

- If not otherwise specified, the term "data" stands for terrain and obstacle data in this document.
- It is recognised there are data that do not meet the stipulated numerical requirements or geographic coverage for a given area. Such data are still useful to the aeronautical community[1] provided the necessary quality characteristics in this document are specified to define the data. Such data should be clearly annotated to identify which values do not meet the quality characteristics, numerical requirements, or geographic coverage for a given area.

[1] Such data can, amongst many other uses, support systems which require less stringent data than that specified in Section 4 of this document or to infill data omissions.

- It is assumed that not all applications will require a complete set of data to enable intended use. That is, all data types may not be necessary for certain applications. Requirements specified in this document need only be complied with for those data that are needed for an application.
- An agreed standard data model and complementary data exchange format will be established. The development of this model and exchange format is outside the scope of this document.

1.5 Section Synopsis

Section 2 Terrain and Obstacle Data Definitions establishes the obstacle and terrain definitions from which this document is based.

Section 3 Terrain and Obstacle Attributes presents the main requirements applicable to the attributes used in subsequent sections.

Section 3.1 introduces terrain and obstacle attributes.

Section 3.2 defines the set of attributes that need to be taken into account in order to describe terrain data and the requirements applicable to those attributes.

Section 3.3 defines the set of attributes that need to be taken into account in order to describe obstacle data and the requirements applicable to those attributes.

Section 4 Numerical Requirements provides numerical figures for some of the terrain and obstacle attributes, according to specific area defined here, and applications, which are potentially the most likely to be implemented.

Section 4.1 introduces applications that require terrain and obstacle data.

Section 4.2 introduces the four areas of coverage that have been defined.

Section 4.3 describes area 1 – The world and provides numerical requirements for some of the attributes.

Section 4.4 describes area 2 – The terminal airspace and provides numerical requirements for some of the attributes.

Section 4.5 describes area 3 – Cat II and III operation area and provides numerical requirements for some of the attributes.

Section 4.6 provides matrices, which summarise the numerical requirements for both terrain and obstacle databases.

Section 4.7 provides numerical requirements applicable to terrain data, from an aerodrome mapping prospective.

Section 5 Quality Management presents the main quality requirements applicable to terrain and obstacle databases in addition to those specified in EUROCAE ED-76/RTCA DO-200A.

Section 5.1 introduces quality management concepts.

Section 5.2 provides traceability requirements.

Section 5.3 provides quality assurance requirements for databases.

Section 5.4 describes the various types of errors that can affect the quality of a terrain and obstacle database.

Section 5.5 discusses terrain and obstacle data integrity versus system integrity.

Section 6 Certification Guidelines provides guidance material to be considered when dealing with the certification of equipment or an application relying on the use of a terrain and/or obstacle database. Such recommendations are applicable along the data chain.

Section 6.1 introduces the terrain database generation phases and provides guidance applicable to terrain data for each of the phases.

Section 6.2 introduces the obstacle database generation phases and provides guidance applicable to obstacle data for each of the phases.

Section 6.3 provides some recommendations applicable to the maintenance of databases.

Appendix A is a glossary of terms used in this document.

Appendix B provides a list of abbreviations and acronyms.

Appendix C provides further information about the various existing or envisaged applications based on the use of terrain and obstacle databases.

Appendix D provides background information on the type of errors that can affect the quality of a database.

Appendix E provides information related to different methods currently available in order to originate terrain data.

Appendix F is a list of references for the entire document.

Appendix G is the membership list of EUROCAE WG 44 / RTCA SC 193.

Figure 1.2 shows where the requirements that are provided in the document apply within the terrain and obstacle data flow. Furthermore, it highlights the need to follow the guidance provided in the EUROCAE ED-76/RTCA DO-200A for the data development process.

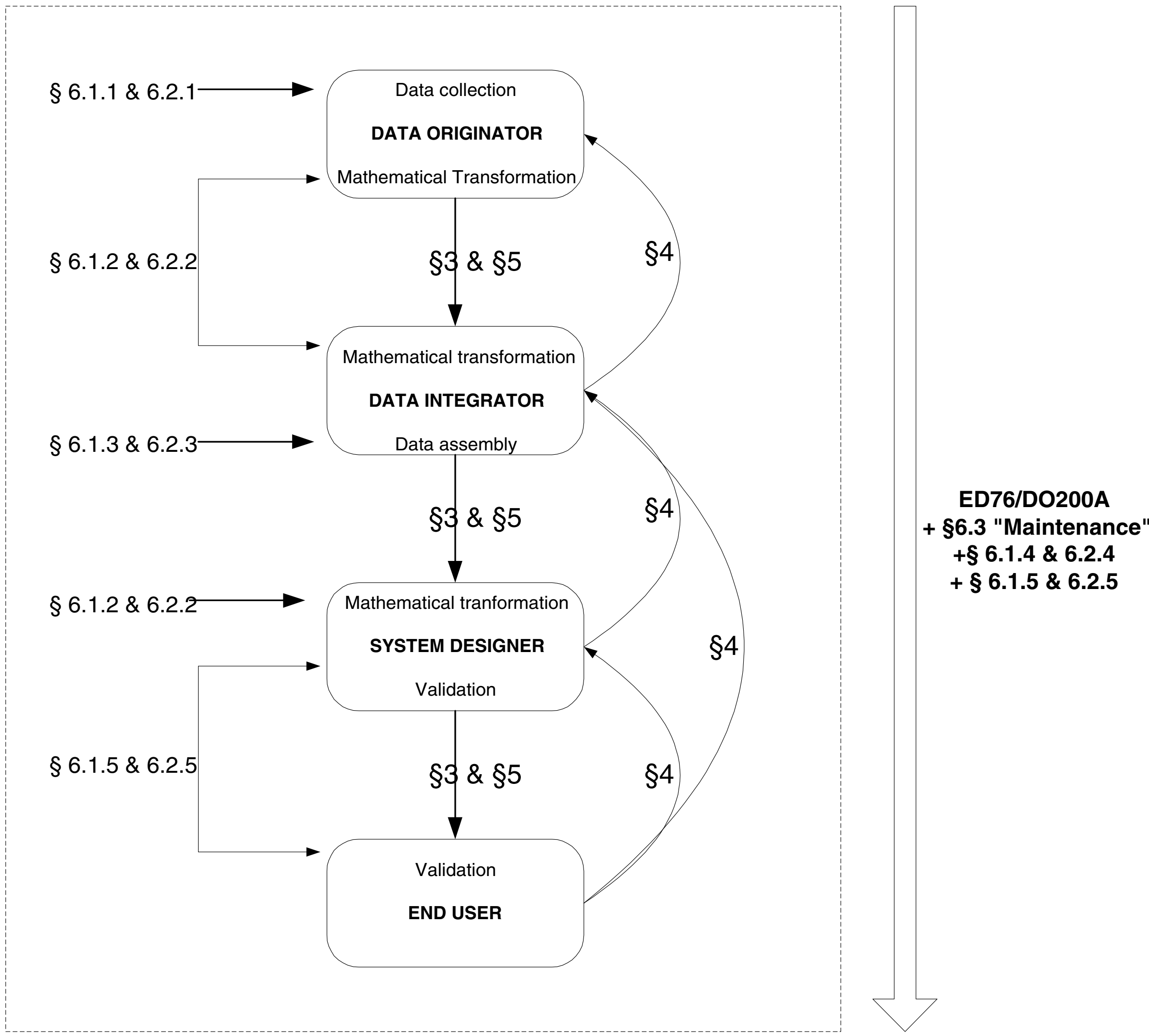


Figure 1-2 Application of This Standard Within the Terrain and Obstacle Data Flow

1.6 Comments

The editorial practices of ICAO were followed in writing each section. Where the requirements in this document are intended as a (mandatory) standard, the operative verb “shall” is used. Where the requirements in this document are desirable, the operative verb “should” is used.

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2 TERRAIN AND OBSTACLE DATA DEFINITIONS

2.1 Introduction

This section gives a definition for the terms terrain, obstacle, and significant obstacles. It provides guidance to distinguish between the three terms. Understanding and distinguishing among these terms is key for the generation of aviation databases.

2.2 Definitions

Two examples of geospatial databases are terrain and obstacle databases.

Depending on the source of information, a terrain database may describe something between “bare earth” and “bare earth with cultural features and/or obstacles” (canopy, buildings, etc.).

However, for the purpose of this document, terrain and obstacle are used according to the following definitions:

Note: *The following definitions do not conform with those published by ICAO as the latter were found to be limited in their scope.*

- **Terrain:** The natural surface of the earth excluding obstacles.

Note: *In practical terms, this will represent the continuous surface that exists at the bare earth, the top of the vegetation canopy, or something in-between as presented in figure 2.1. See sections 3.2.17 “Surface Type”, 3.2.18 “Recorded Surface”, 3.2.19 “Penetration Level” and Appendix E: Remote Sensing Technologies for amplification.*

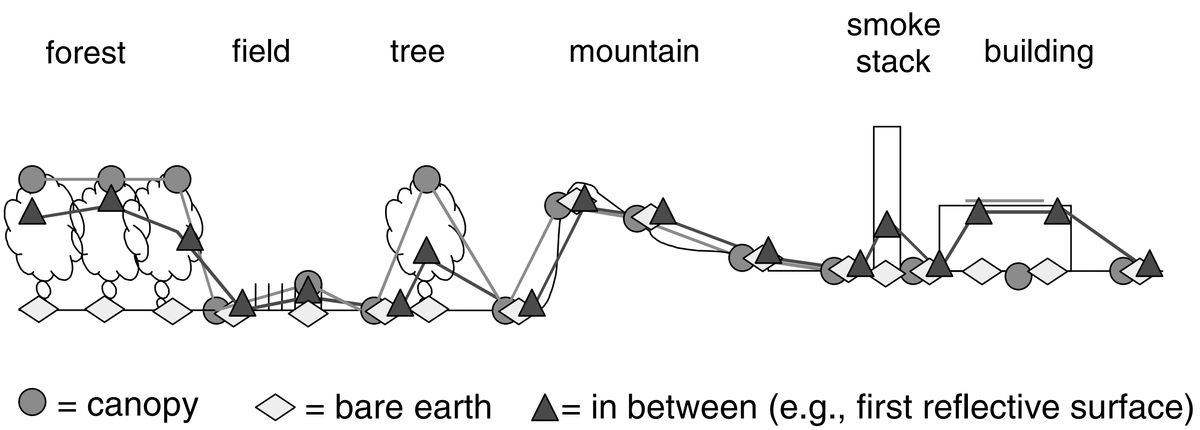
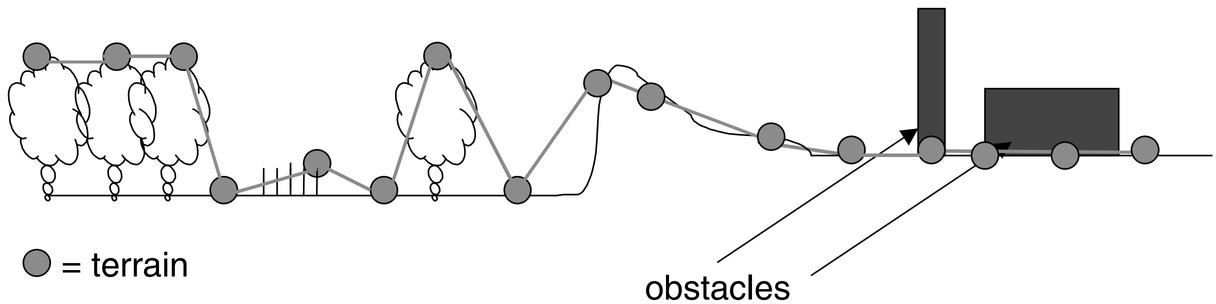


Figure 2-1 Terrain Definition

- **Obstacle:** An individually identified object of limited spatial extent (see figure 2.2).

Note: *Some of the object’s characteristics are captured in the database. Obstacles are not included in the terrain database. Obstacles may be temporary or permanent, fixed or movable, an example of the latter being a ship. Many important data elements are features and not just elevations. Obstacles may be represented by points, lines or polygons.*



Note: *In certain databases, the single tree and/or the forest in this figure may be considered as an obstacle.*

<u>Figure 2-2</u> Obstacle Definition

- Significant obstacle: Any natural terrain feature or man-made fixed object, permanent or temporary, which has vertical significance in relation to adjacent and surrounding features and which is considered a potential hazard to the safe passage of aircraft in the type of operation for which the terrain and obstacle data are used.

Note: *The term "significant obstacle" is used in ICAO Annex 4 solely for the purpose of specifying the objects to be included on charts. Obstacles are specified in other terms in Annex 14, Volumes I and II, for the purpose of clearing and marking.*

3 TERRAIN AND OBSTACLE DATA ATTRIBUTES

3.1 Introduction

This section defines a minimum set of attributes for Terrain and Obstacle databases. However, it should be noted that nothing restricts a user from defining or adding new attributes in addition to this minimum set of attributes. It is assumed that these databases will provide historical traceability from origination in accordance with EUROCAE ED-76/RTCA DO-200A.

3.2 Terrain Data Attributes

A terrain database is a digital representation of the vertical extent (elevation) of the terrain at a number of discrete points. Terrain databases are also referred to as digital elevation models (DEMs), digital terrain models (DTMs), and digital surface models (DSMs). Terrain databases consist of a regular or irregular distribution of points. Major features of a terrain database include geometric distribution/position of discrete points, horizontal/vertical datum and specific units of measurement.

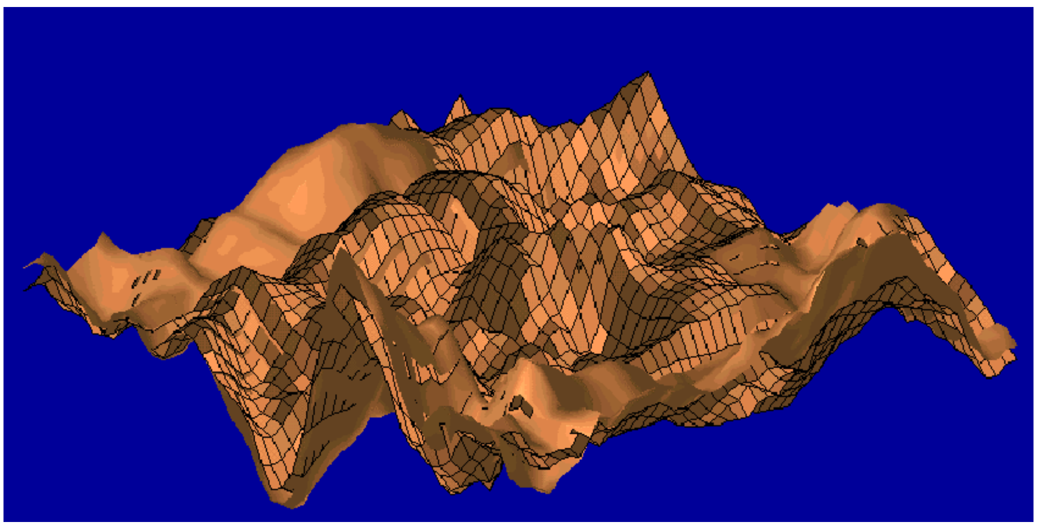
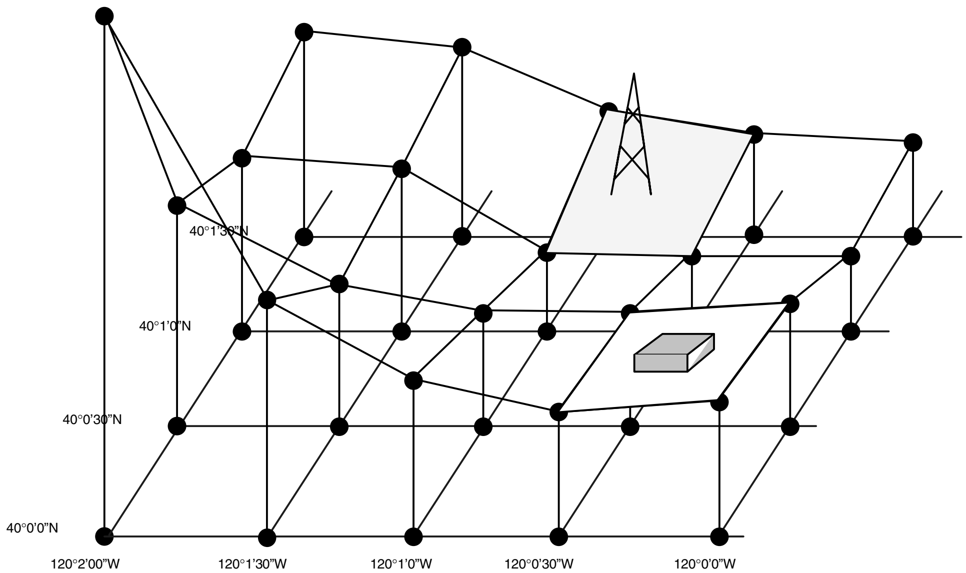


Figure 3-1 Example of a Terrain Database Represented as a DEM

Terrain may be depicted on a grid of elevations determined at regular sample points. The resultant is a Digital Elevation model (DEM) represented below in figure 3.2.



<u>Figure 3-2</u> Diagram of a Bare Earth Digital Terrain Elevation Model Depicted as a Terrain Grid of Elevations at Regular Sample Points

The x,y locations are the longitude and latitude, respectively and the vertical extent is the terrain elevation. This terrain grid is represented by a terrain database. In this figure, obstacles such as a tower and a building have been overlayed on the terrain grid to demonstrate that obstacle heights are relative to the terrain height. These obstacles are captured in obstacle database.

The following table 3.1 presents the list of attributes that have been defined to describe terrain data.

- Attributes that are designated “required” shall be recorded.
- It is recommended that “optional” attributes should be recorded.

Table 3-1 Terrain Attributes

Attribute	Required/Optional	Section
Area of Coverage	Required	§3.2.1
Data Source Identifier	Required	§3.2.2
Acquisition Method	Required	§3.2.3
Post Spacing	Required	§3.2.4
Horizontal Reference System	Required	§3.2.5
Horizontal Resolution	Required	§3.2.6
Horizontal Accuracy	Required	§3.2.7
Horizontal Confidence Level	Required	§3.2.8
Horizontal Position Data	Required	§3.2.9
Elevation	Required	§3.2.10
Database Units	Required	§3.2.11
Elevation Reference	Required	§3.2.12
Vertical Reference System	Required	§3.2.13
Vertical Resolution	Required	§3.2.14
Vertical Accuracy	Required	§3.2.15
Vertical Confidence Level	Required	§3.2.16
Surface Type	Optional	§3.2.17
Recorded Surface	Required	§3.2.18
Penetration Level	Optional	§3.2.19
Known Variations	Optional	§3.2.20
Integrity	Required	§3.2.21
Time Stamp	Required	§3.2.22

3.2.1 Area of Coverage

Area of coverage is a descriptor used to identify the boundary of the terrain data. The intent of this attribute is to help the user identify in general terms the area under consideration. The shape of the coverage may be a polygon (e.g., Lat 30N to Lat 40N, Long 80W to Long 90W).

3.2.2 Data Source Identifier

Data source identifier uniquely identifies the data originator.

- Sufficient information shall be provided to distinguish among multiple data originators.
- A permanent record of the originator shall be kept to establish an audit trail.

3.2.3 Acquisition Method

The acquisition method used to obtain the data shall be defined.

Note: *This attribute may be used, in conjunction with the surface type, to better understand the measurement properties.*

3.2.4 Post Spacing

Post spacing is the distance (angular or linear) between two adjacent elevation points. It should be noted that the latitude post spacing might be different from the longitude post spacing.

Terrain database post spacing is presented in both angular and linear units to provide general guidance about the required density of measurement points. The linear measure is an approximation of the angular requirement near the equator.

Angular increments may be adjusted when referencing high latitude regions to maintain a constant linear density of measurement points.

- When linear and angular post-spacing requirements differ, the linear requirement shall take precedence.

3.2.5 Horizontal Reference System

The horizontal reference system is the datum to which the positions of the data points are referenced.

- ICAO Standards and Recommended Practices (SARPs) require that coordinates used for air navigation shall be expressed in the WGS-84 reference system.
- If the horizontal reference system is not WGS-84, the reference system and transformation parameters to WGS-84 shall be specified. (For amplification, see Appendix D, section D.1)

3.2.6 Horizontal Resolution

Horizontal resolution is the degree of separation with which the measurements are taken. Horizontal resolution can have two components:

- The units used in the measurements. Position recorded in one-arc second increments has a higher resolution than that taken in one-arc minute increments.
- The number of decimal places for the recording of the position. Use of more decimal places can provide for higher resolution.

It is important to note that resolution and post spacing are not synonymous and can be confused with each other. Horizontal resolution is the number of decimal places in the measurement of the position, e.g. 0.1 arc second.

3.2.7 Horizontal Accuracy

Horizontal accuracy specifies the degree of closeness of the position values of the data-points to their true position.

- Horizontal accuracy shall be stated in the same units as used for the elevation.
- The statistical derivation of the horizontal accuracy shall be stated.
- Bias and standard deviation should be provided. (For further details see Appendix D)

3.2.8 Horizontal Confidence Level

Horizontal confidence level specifies the probability that the position values are within the stated horizontal accuracy of the true position.

- The confidence level of the position shall be stated, e.g. as a percentage.
- Confidence level shall be expressed as the probability that any single location in the data set is in error of the true position by less than the stated horizontal accuracy.

Note: *A 90% confidence level implies that there is no more than a 10% probability that the difference between any position value for an elevation in the database and the true position of the elevation is greater than the stated horizontal accuracy (For further details see Appendix D).*

3.2.9 Horizontal Position Data

Horizontal position data are defined by geodetic latitude and longitude. The geodetic latitude of a point is defined as the angle between the normal to the ellipsoid at that point, and the equatorial plane. The geodetic longitude of a point is the angle between its geodetic meridian plane and the IRM (IERS Reference Meridian).

However, it is recognised that some terrain databases use projection-based co-ordinates (e.g. Universal Transverse Mercator (UTM) Eastings and Northings).

- These terrain databases shall have a projection type attribute.
- Latitude – The format for latitude, the north-south component of location, shall be expressed, e.g. degree, minutes, seconds or decimal degrees.
- Longitude – The format for longitude, the east-west component of location, shall be expressed, e.g. degree, minutes, seconds or decimal degrees.

3.2.10 Elevation

Elevation is the vertical distance of a point or a level, on or affixed to the surface of the earth measured from mean sea level.

- Elevation shall be expressed in linear units that are consistent with the accuracy and resolution specifications.

3.2.11 Database Units

For every attribute that requires it,

- the units used shall be stated and
- the units shall be consistent within the database.

3.2.12 Elevation Reference

Elevation reference may be represented by one of the following:

1. The provided values may correspond to a particular corner or the centre of a DEM cell, the mean elevation value of the cell, the maximum elevation value, etc;
2. In a regularly distributed grid (i.e., square, rectangular) the first data point of the set is the reference point with a known recorded planimetric position, to which the other data points are referenced;
3. When the data represent the terrain elevation at specific latitude/longitude points, then the terrain elevation between the database sample points may be higher or lower than the database values.

    - For every data set, the point of the cell that is used to provide the reference elevation value shall be explicitly defined.

3.2.13 Vertical Reference System

The vertical reference system is the datum to which the elevation values are referenced:

- The Geoid (Mean Sea Level)
- It is recognised that one common earth gravitational model should be adopted as an ICAO standard (e.g. EGM 96). As a first stage in global harmonisation and ahead of the adoption of a common earth gravitational model published as a standard by ICAO suitable for all aviation uses, the use of EGM 96 is recommended.
- WGS 84 shall be the ellipsoid in accordance with the ICAO Annex 15.

3.2.14 Vertical Resolution

Vertical resolution is the degree of separation with which the measurements are recorded. Vertical resolution can have two components:

- The units used in the measurements. Elevation recorded in one-foot increments has a higher resolution than that taken in one-meter increments;
- The number of decimal places for the recording of the elevation. Use of more decimal places can provide for higher resolution.

3.2.15 Vertical Accuracy

Vertical accuracy specifies the degree of closeness of the recorded elevation values to the true elevation.

- Vertical accuracy shall be stated in the same units as used for the elevation.
- The statistical derivation of the vertical accuracy shall be stated.
- Bias and standard deviation should be provided. (For further details see Appendix D).

3.2.16 Vertical Confidence Level

Vertical confidence level specifies the probability that the position values are within the stated vertical accuracy of the true elevation.

- The confidence level of the elevation shall be stated, e.g. as a percentage.
- Confidence level shall be expressed as the probability that any single location in the data set is in error of the true elevation by less than the stated vertical accuracy.

Note: *A 90% confidence level implies that there is no more than a 10% probability that the difference between any elevation value for an elevation in the database and the true elevation is greater or less than the stated vertical accuracy (For further details see Appendix D).*

3.2.17 Surface Type

Surface type is a classification of the recorded surface, e.g., marshland, water, permanent ice, etc…

3.2.18 Recorded Surface

Recorded surface identifies the surface that the elevation data represent. Some examples of surfaces that may be recorded by available technologies are:

1. The ***bare earth*** recorded by land survey or in remote sensing techniques when vegetation or snow/ice is not present.
2. The ***reflective surface*** recorded by either an active sensor or a passive sensor.
3. The sensor equipment manufacturer or the service provider shall identify the surface that has been recorded.

3.2.19 Penetration Level

The Recorded Surface attribute identifies the surface the elevation data represent. When the position of this surface, between the bare earth and top of the canopy or the surface of snow or ice is known, it should be recorded in the attribute "Penetration Level". Nevertheless, when recorded by either active or passive remote sensors, it is recognised that the degree of penetration of the sensor signal is frequently impossible to determine precisely. The estimated penetration will be expressed as a unit of measurement e.g. meter or feet.

Note: *For the purpose of this document, it is important for the reader to understand the impact of sensor penetration on the accuracy of recorded values. Photographic cameras that record information from every reflective object are one* *example of a passive sensor. Active sensors radiate energy and the reflected energy that returns to the sensor is used to determine heights. Some sensors detect reflected energy from the top of the forest canopy or ice surface and others will collect reflected energy which has penetrated to bare terrain or somewhere in between. The actual or estimated penetration level, if known, is to be recorded in the attribute "Penetration Level".*

3.2.20 Known Variations

Known variations specify predictable changes to the data e.g., seasonal elevation changes due to snow accumulations or vegetation growth.

3.2.21 Integrity

Integrity of data is the degree of assurance that the data and its value have not been lost nor altered since the data origination or authorised amendment.

- The integrity of the data set shall be expressed, indicating the probability of any single data element having been changed inadvertently since the creation of the data set.

Note: *For more information on integrity, refer to EUROCAE ED-76/RTCA DO-200A.*

3.2.22 Time Stamps

Time stamps are information about the origination or modification date/time of the data. Time stamps should refer to Universal Co-ordinated Time (UTC), otherwise the reference time should be specified.

3.3 Obstacle Data Attributes

An obstacle is an individually identified object of limited spatial extent. Some of the object's characteristics are captured in the database. Obstacles are not included in the terrain database. Obstacle data elements are features, which may be represented by points, lines or polygons.

Note: *Obstacles may be temporary or permanent, fixed or movable, an example of the latter being a ship.*

Obstacle data are comprised of the digital representation of the vertical and horizontal extent of man-made and natural significant features such as isolated rock pillars and natural vegetation (trees).

Obstacle data include those features which have vertical significance in relation to adjacent and surrounding features and which are considered as potential hazards for aviation purposes. The definition of obstacles, which are considered a potential hazard for aviation purposes are to be found in appropriate ICAO or national documents.[1]

Specific attributes attached to moveable or temporary obstacles are not included in this document.

[1] ICAO Annex 4, Annex 15, PANS OPS, FAA TERPS

The following represent the minimum number of attributes that shall be recorded for obstacle data that will be used in aviation applications.

Table 3-2 Obstacle Attributes

Attribute	Section
Area of Coverage	§3.3.1
Data Source Identifier	§3.3.2
Horizontal Position Data	§3.3.3
Horizontal Reference System	§3.3.4
Horizontal Resolution	§3.3.5
Horizontal Extent	§3.3.6
Horizontal Accuracy	§3.3.7
Horizontal Confidence Level	§3.3.8
Elevation	§3.3.9
Height	§3.3.10
Database Units	§3.3.11
Vertical Reference System	§3.3.12
Vertical Resolution	§3.3.13
Vertical Accuracy	§3.3.14
Vertical Confidence Level	§3.3.15
Obstacle Type	§3.3.16
Integrity	§3.3.17
Time Stamps	§3.3.18

3.3.1 Area of Coverage

Area of coverage is a descriptor used to identify the boundary of the obstacle data. This should be used to help the user identify in general terms the area under consideration. (e.g., Cell phone towers in Finland, Navaids at a particular airport).

3.3.2 Data Source Identifier

Data source identifier uniquely identifies the data originator:

- Sufficient information shall be provided to distinguish between multiple data originators.
- A permanent record of the originator shall be kept to establish an audit trail.

3.3.3 Horizontal Position Data

Horizontal position data shall be expressed for a point, or points defining a line or a polygon, e.g., by latitude and longitude. Refer to 3.2.9

3.3.4 Horizontal Reference System

The horizontal reference system is the datum to which the positions of the data points are referenced.

- ICAO Standards and Recommended Practices (SARPs) require that coordinates used for air navigation shall be expressed in the WGS-84 reference system.
- If the horizontal reference system is not WGS-84, the reference system and transformation parameters to WGS-84 shall be specified. (For amplification, see Appendix D, section D.1)

3.3.5 Horizontal Resolution

Horizontal resolution is the degree of separation with which the measurements are taken. Horizontal resolution can have two components:

- The units used in the measurements. Position recorded in one-arc second increments has higher resolution than that taken in one-arc minute increments.
- The number of decimal places for the recording of the position. Use of more decimal places can provide for higher resolution.

Horizontal resolution is be the number of decimal places in the measurement of the position, e.g. 0.1 arc second.

3.3.6 Horizontal Extent

The horizontal extent is the footprint of or the area subtended by the obstacle, e.g. area covered by mast guy wires, or weather balloon.

3.3.7 Horizontal Accuracy

Horizontal accuracy specifies the degree of closeness of the position values of the obstacle to its true position.

- It shall be stated in the same units as used for the elevation.
- The statistical derivation of the horizontal accuracy shall be stated.
- Bias and standard deviation should be provided. (For further details see Appendix D)

3.3.8 Horizontal Confidence Level

Horizontal confidence level specifies the probability that the position values are within the stated horizontal accuracy of the true position.

- The confidence level of the position shall be stated, e.g. as a percentage.
- Confidence level shall be expressed as the probability that any single location in the data set is in error of the true position by less than the stated horizontal accuracy.

Note: *A 90% confidence level implies that there is no more than a 10% probability that the difference between any position value for an obstacle in the database and the true position of the obstacle is greater than the stated horizontal accuracy (For further details see Appendix D).*

3.3.9 Elevation

Elevation is the vertical distance of a point or a level, on or affixed to the surface of the earth measured from the vertical reference system as specified in 3.3.12 (mean sea level).

- For points, the elevation shall be the altitude of the top of the obstacle.
- For lines, the elevation shall be given for each point defining the line.
- For polygons, the elevation shall be given by the maximum height within the polygon.
- Elevation shall be expressed in linear units that are consistent with the accuracy and resolution specifications.

3.3.10 Height

Height is the vertical distance of a level, point or an object considered as a point, measured from a specific datum.

- Obstacle heights shall be referenced to the ground level (AGL).
- For points, the height shall be the top of the obstacle.
- For lines, the height shall be given for each point defining the line.

- For polygons, the height shall be the maximum height within the polygon.
- Height shall be expressed in a format that is consistent with the accuracy and resolution specifications.

3.3.11 Database Units

For every attribute that requires it,

- The units used shall be stated and
- The units shall be consistent within the database.

3.3.12 Vertical Reference System

The vertical reference system is the datum to which the elevation values are referenced.

The Geoid (Mean Sea Level)

It is recognised that one common earth gravitational model is expected to be adopted as an ICAO standard. As a first stage in global harmonisation and ahead of the adoption of a common earth gravitational model published as a standard by ICAO suitable for all aviation uses, the use of EGM 96 is suggested. It should be noted that in some parts of the world, EGM 96 is not suitable for sub-metric aviation use.

Note: *It is recognized that the WGS-84 ellipsoid can also be used as a vertical reference system. In these cases, the geoid undulation (difference between ellipsoid and geoid) can be used to change the reference.*

3.3.13 Vertical Resolution

Vertical resolution is the degree of separation with which the measurements are taken. Vertical resolution can have two components:

- The units used in the measurements. Elevation recorded in one-foot increments has higher resolution than that taken in one-meter increments.
- The number of decimal places for the recording of the elevation. Use of more decimal places can provide for higher resolution.

Vertical resolution is the number of decimal places in the measurement of the elevation, e.g. 0.1 meters.

3.3.14 Vertical Accuracy

Vertical accuracy specifies the degree of closeness of the recorded elevation values to the true elevation.

- Vertical accuracy shall be stated in the same units as used for the elevation.
- The statistical derivation of the vertical accuracy shall be stated.

Bias and standard deviation should be provided. (For further details see Appendix D).

3.3.15 Vertical Confidence Level

Vertical confidence level specifies the probability that the position values are within the stated vertical accuracy of the true elevation.

- The confidence level of the elevation shall be stated, e.g. as a percentage.
- Confidence level shall be expressed as the probability that any single location in the data set is in error of the true elevation by less than the stated vertical accuracy.

Note: *A 90% confidence level implies that there is no more than a 10% probability that the difference between any elevation value for an elevation in the database and the true elevation is greater than the stated vertical accuracy. (For further details see Appendix D).*

3.3.16 Obstacle Type

Obstacle type is a description of the recorded obstacle, e.g., tower, building, tree, power-lines, windmill farms, or cable car.

Obstacles may be temporary such as cranes, permanent such as TV transmission towers, moving, such as ships.

3.3.17 Integrity

Integrity of data is the degree of assurance that the data and its value have not been lost nor altered since the data origination or authorised amendment.

- The integrity of the data set shall be expressed, indicating the probability of any single data element having been changed inadvertently since the creation of the data set.

Note: *For more information on integrity, refer to EUROCAE ED-76/RTCA DO-200A.*

3.3.18 Time Stamps

Time stamps are information about the origination or modification date/time of the data. Time stamps should refer to Universal Coordinated Time (UTC), otherwise the reference time should be specified.

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4 NUMERICAL REQUIREMENTS

4.1 Introduction

The following defines the obstacle and terrain requirements for originated data necessary to accommodate the most stringent known application requirements. It is recognised that some current applications have less demanding requirements and that enhanced capabilities or services may be provided with data of a better quality. Future applications may necessitate additional requirements.

The integrity, accuracy, and resolution requirements specified in this document and the completeness of resulting databases are not necessarily sufficient for primary means of navigation. The numerical values shown are not to be construed as system level or application specific requirements. System level or application specific requirements are dependent on a safety analysis of the entire system, of which the database is only one part. The following are examples of the many applications that use obstacle and terrain data:

- Terrain Awareness and Warning System (TAWS)
- Off Airway RNP Drift-Down Protection
- Emergency Landing Site Selection
- Synthetic Vision Systems
- Minimum Safe Altitude Warning (MSAW)
- Instrument Procedure Design
- Operator Engine-Out Procedure Analysis
- Simulation/Flight Crew Familiarisation in Terminal Airspace
- Advanced Surface Movement
- Charting

Applications listed above (except advanced surface movement and charting) are addressed in Appendix C.

4.2 Areas of Coverage

For the purpose of this document, the requirements for accuracy, integrity and resolution are provided for the following areas:

- Area 1 – The World
- Area 2 – The Terminal Airspace
- Area 3 – CAT II or III Operation Area

EUROCAE ED 98/RTCA DO 272 specifies the requirements for accuracy, integrity and resolution for the Aerodrome Mapping Area.

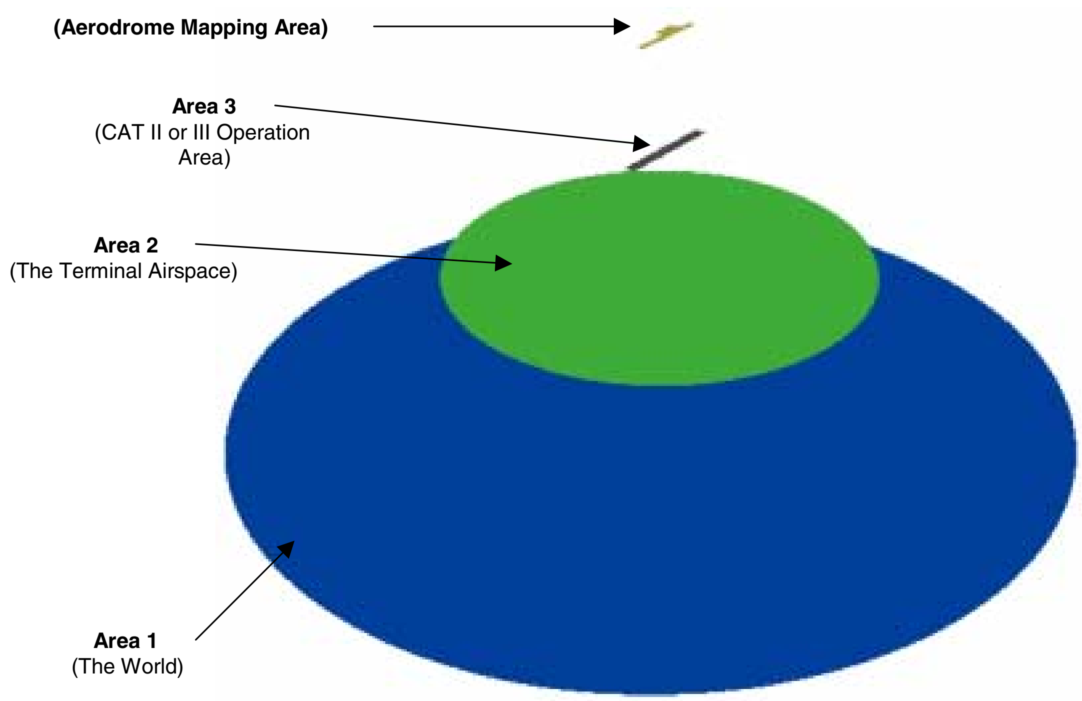


Figure 4-1 Areas of Coverage

4.3 Area 1 – The World

Area 1 covers the entire world. The numerical requirements for terrain and obstacles in Area 1 were derived from existing SARPs for en-route obstacles adjusted to reflect digital needs and can be supported by present and anticipated survey techniques.

- Every obstacle within Area 1 whose height above the ground is equal to or greater than 100 m is considered a significant obstacle to be included in obstacle databases.

Table 4.1 presents the numerical requirements for obstacle data in Area 1 – The World.

Table 4-1 Obstacle Data Requirements for Area 1 – The World

Areas/Attributes	Area 1 - Continuous (The World)
Horizontal Accuracy	50.0 m
Data Integrity	Routine (10^{-3})
Vertical Accuracy	30.0 m
Vertical Resolution	1.0 m
Confidence Level	90%

Table 4.2 presents the numerical requirements for terrain data in Area 1 – The World.

Table 4-2 Terrain Data Requirements for Area 1 – The World

Areas/Attributes	Area 1 - Continuous (The World)
Horizontal Accuracy	50.0 m
Data Integrity	Routine (10^{-3})
Vertical Accuracy	30.0 m
Vertical Resolution	1.0 m
Confidence Level	90%
Terrain Database Post Spacing	3 arc second (100 m)

4.4 Area 2 – The Terminal Airspace

Area 2 is the terminal airspace as defined in the Aeronautical Information Publication (AIP) of the State, limited to a maximum of 45 km from the ARP. For airfields which do not have a legally defined Terminal Area (TMA), Area 2 is the area covered by a radius of 45 km from the ARP excluding sub areas where flight operations are restricted due to high terrain or "no fly" conditions.

4.4.1 Area 2 Obstacles

Significant obstacles in Area 2 (see Fig. 4.2) are defined as any of the following:

- Any obstacle with a height above the ground of 1 m or more within 100 m of both sides of the runway centreline and abeam the runway or clearway (if a clearway exists).
- Any obstacle that penetrates a surface starting 100 m on both sides of the runway centreline and at 1 m above the nearest runway centreline elevation, and extending 1.2% until reaching 75 m above the lowest elevation of all runway surfaces. This slope of 1.2% reaches a height of 75m at approximately 6 km.
- Any obstacle 75 m or higher above the lowest elevation of all runway surfaces in the remainder of Area 2.

Note: *The surface described above is the Area 2 obstacle assessment surface.*

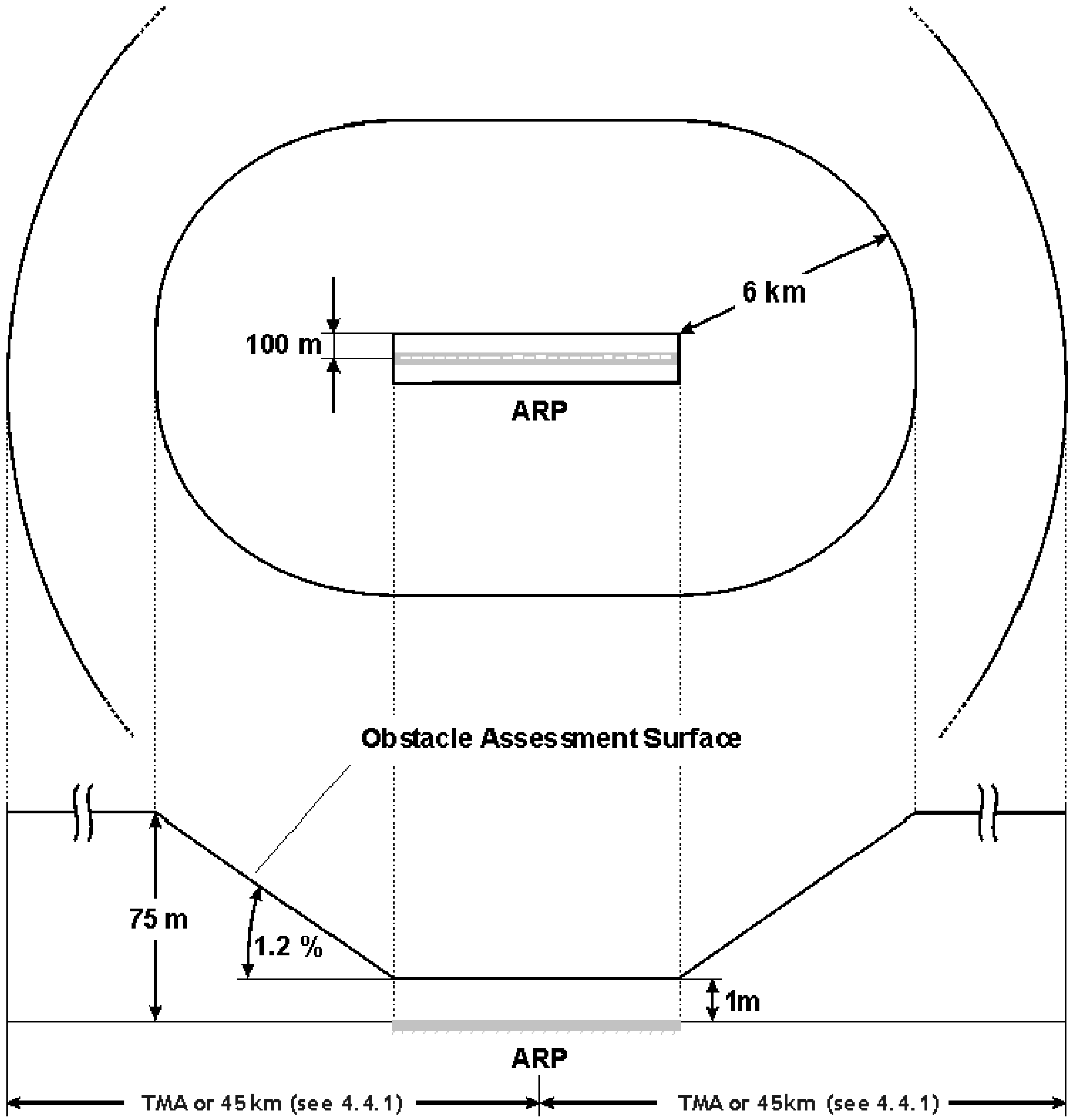


Figure 4-2 Area 2 Significant Obstacles

Every significant obstacle shall be recorded with the following numerical requirements.

Table 4-3 Obstacle Data Requirements for Area 2

Areas/Attributes	Area 1 - Continuous (The World)
Horizontal Accuracy	5.0 m
Data Integrity	Essential (10^{-5})
Vertical Accuracy	3.0 m
Vertical Resolution	0.1 m
Confidence Level	90%

4.4.2 Area 2 Terrain

- Within a radius of 10 km, terrain shall be recorded with the Area 2 numerical requirements provided in Table 4.4, excluding sub areas where flight operations are restricted due to high terrain or “no fly” conditions which are included in Area 1.
- Terrain located between 10 and 45 km from the ARP that penetrates the Area 2 obstacle assessment surface shall be recorded with the Area 2 numerical requirements.
- Terrain located between 10 km and 45 km from the ARP that does not penetrate the Area 2 obstacle assessment surface shall be recorded to Area 1 numerical requirements.

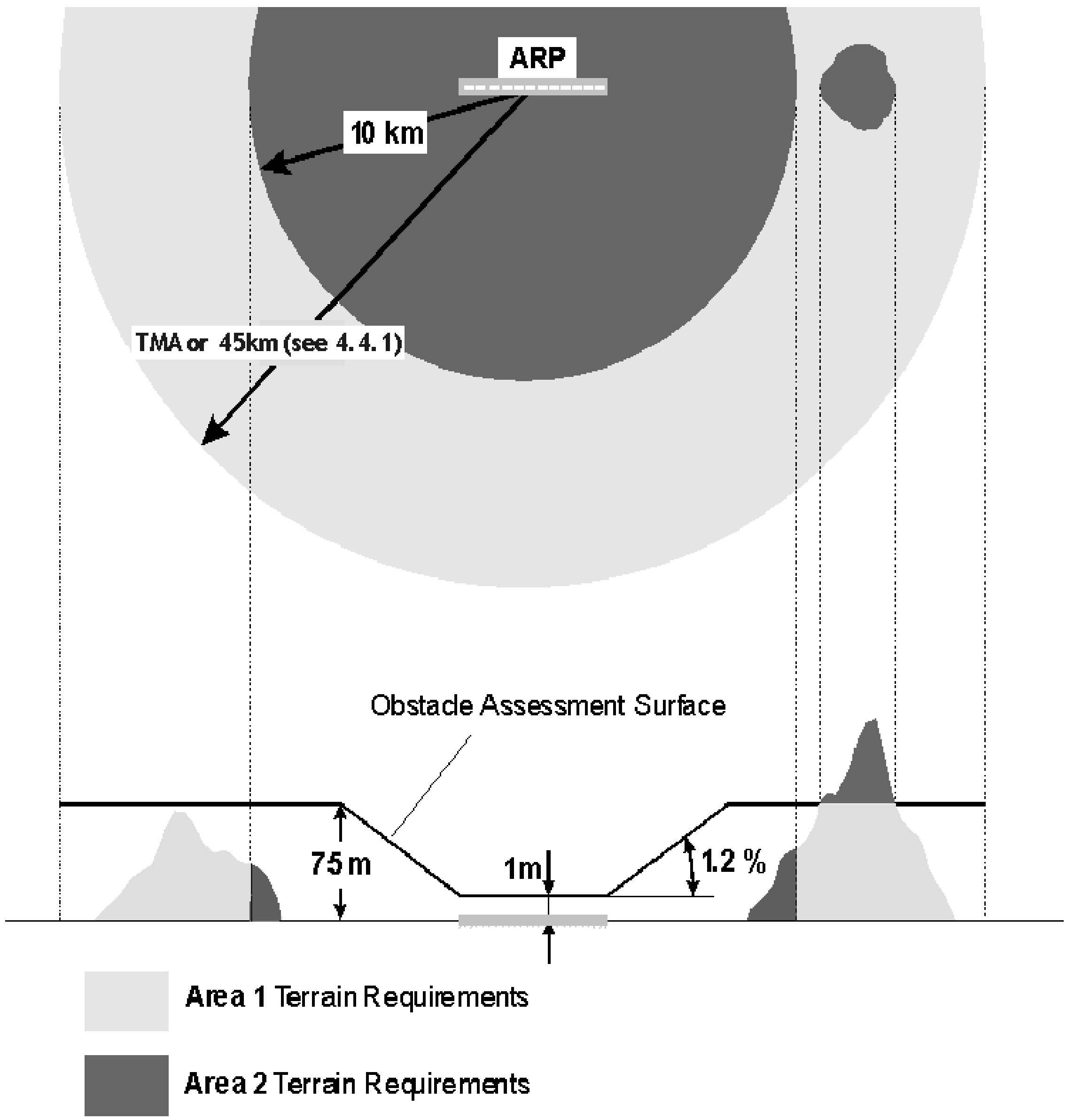


Figure 4-3 **Area 1 and 2 for Terrain**

Table 4-4 Terrain Data Requirements for Area 2

Areas/Attributes	Area 2 – Terminal Airspace
Horizontal Accuracy	5.0 m
Data Integrity	Essential (10^{-5})
Vertical Accuracy	3.0 m
Vertical Resolution	0.1 m
Confidence Level	90%
Terrain Database Post Spacing	1.0 arc second (30 m)

4.5 Area 3 – CAT II and III Operation Area

Area 3 is defined as the Radar Altimeter Area for CAT II/III Precision Approach procedures. The area extends from the runway threshold to 900 m (3000 ft) from the threshold. It is 120 m (400 ft) wide and centered on an extension of the runway centreline.

Note: *There are no obstacle data requirements associated with Area 3.*

- At those airports where runways are equipped for CAT II or III operations, terrain data requirements for Area 3, provided in Table 4.5, shall apply.

Table 4-5 Terrain Data Requirements for Area 3

Areas/Attributes	Area 3 – CAT II/III Operation Area
Horizontal Accuracy	2.5 m
Data Integrity	Essential (10^{-5})
Vertical Accuracy	1.0 m
Vertical Resolution	0.1 m
Confidence Level	90%
Terrain Publication Timeliness	As required
Terrain Database Post Spacing	0.3 arc second (10m)

4.6 Summary of Numerical Terrain and Obstacle Data Requirements

4.6.1 Obstacle Data Numerical Requirements

Table 4-6 Summary of Obstacle Data Requirements

Areas/Attributes	Area 1 – The World	Area 2 – Terminal Airspace
Horizontal Accuracy	50.0 m	5.0 m
Data Integrity	Routine (10^{-3})	Essential (10^{-5})
Vertical Accuracy	30.0 m	3.0 m
Vertical Resolution	1.0 m	0.1 m
Confidence Level	90%	90%

4.6.2 Terrain Data Numerical Requirements

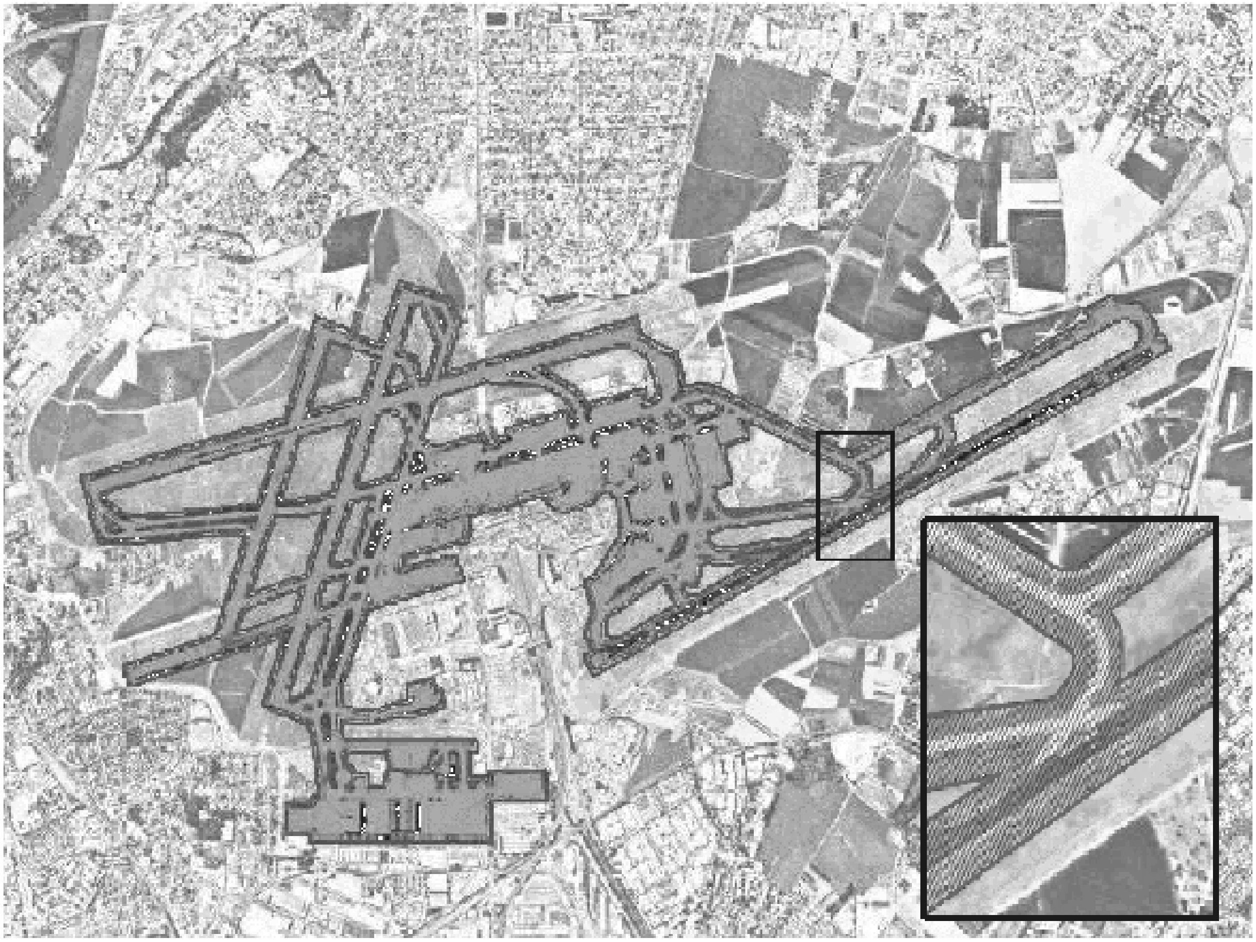
Table 4-7 Summary of Terrain Data Requirements

Areas/Attributes	Area 1 – The World	Area 2 – Terminal Airspace	Area 3 – CAT II/III Operation Area
Horizontal Accuracy	50.0 m	5.0 m	2.5 m
Data Integrity	Routine (10^{-3})	Essential (10^{-5})	Essential (10^{-5})
Vertical Accuracy	30.0 m	3.0 m	1.0 m
Vertical Resolution	1.0 m	0.1 m	0.1 m
Confidence Level	90%	90%	90%
Terrain Database Post Spacing	3 arc second (100m)	1.0 arc second (30m)	0.3 arc second (10m)

4.7 Supplemental Terrain Requirements for Aerodrome Mapping

Aerodrome mapping is addressed in EUROCAE ED-99/RTCA DO-272 "User Requirements for Aerodrome Mapping Information", which establishes requirements for aerodrome databases, but does not address terrain requirements. This section describes the area and the terrain data numerical requirements for digital terrain data supporting applications described in EUROCAE ED-99/RTCA DO-272.

The area required for terrain is defined as the aerodrome surface movement areas plus a buffer of 50 m, or the minimum separation distances specified in ICAO Document 9157, whichever is greater. It should be noted that application of the buffer might result in interior regions that are excluded from this area, as illustrated in Fig. 4.4.



<u>Figure 4-4</u> Exclusion of Interior Region

<u>Table 4-8</u> Terrain Data Numerical Requirements to Support Aerodrome Mapping

Attributes/Areas	Aerodrome Mapping
Horizontal Accuracy	0.5 m
Data Integrity	Essential (10^{-5})
Vertical Accuracy	0.5 m
Vertical Resolution	0.01 m
Confidence Level	95%
Database Post Spacing	20 m

5 QUALITY MANAGEMENT

5.1 Introduction

Guidance material relating to the validation of data is provided in this section. The basic principle is that if less attribute information is available from the early stages, then more effort to demonstrate validity will be needed at the validation stage.

Various types of errors that can affect the quality of a database are described briefly in this section. More detailed information on the subject is provided in Appendix D.

5.2 Traceability

Traceability is the ability to track the history, application or location of an entity by means of recorded identifications (ICAO Annex 15). More specifically, it is the degree to which a system or data product can provide a record of the changes made to that system or product and thereby enable an audit trail to be followed from the end user to the data originator.

- The data originator, integrator, and/or provider shall produce adequate information such that the traceability of a terrain and obstacle database can be maintained according to the above definition and in accordance with EUROCAE ED-76/RTCA DO-200A. Typically, this can be accomplished with the provision of an appropriate data record or attribute for each database element as described in Section 3.

5.3 Quality Assurance

This section supplements EUROCAE ED-76/RTCA 200A for the quality assurance of terrain and obstacle data.

- When originators, integrators, and system designers are unable to demonstrate compliance with the requirements of this section the related data shall require testing by using validation, logical consistency, or other means to be agreed upon by the organisation that approves the application.
- When multiple databases are employed for validation, the available meta-data shall be used to demonstrate independence of each data set. Two sets of measurements provided by the same company, using the same data collection technology may induce a bias, either in the initial collection, or in the post-processing techniques used for acquisition and sampling. Furthermore, differences between the data should be identified and compared to the requirements specified for the application.

5.4 Errors

5.4.1 Types of Errors

Errors in terrain and obstacle databases can be classified into three types: Random Errors, Blunders, and Systematic Errors. (For further details see Appendix D.) With respect to data acquisition for terrain and obstacle databases, statistical methods should be applied in order to assess the random errors. Digital filters, based on statistical principles should be used in order to locate and eliminate blunders.

Deterministic procedures should be adopted to correct systematic errors, or the systematic errors should be taken into consideration in the derived statistics. Each data acquisition method introduces its own systematic effect or bias. To eliminate this effect or bias there are two recommended approaches:

1. The use of an appropriate mathematical model that describes the systematic effect (e.g. earth curvature, refraction, etc.)

2. The use of extended models to account for a combination of systematic effects of known sources and quasi-random effects. A typical example is the auto-calibration used in photogrammetric aero-triangulation.

5.4.2 Errors that Affect the Confidence Level of a Database

Point estimation is the estimation of the mean, variance, and covariance of a random variable from sample data. It is only possible to estimate a probability that the true value of the parameter in question is within a certain interval around the estimate. This probability is referred to as the Confidence Level. The confidence level of a terrain and obstacle database is directly related to the lowest confidence level for any existing random variable in the database. Any type of error may affect the confidence level of the database, but systematic and blunder errors will have a larger impact. Therefore, to achieve high confidence levels, it is critical to locate and eliminate these systematic and blunder-type errors.

5.4.3 Accuracy and Precision

The main difference between precision and accuracy lies in the possible presence of bias or systematic error. Although precision includes only random error, accuracy comprises both random and systematic errors. Both terms are used often with the same meaning. In surveying practice, for the majority of cases, the true value is not known and only a most probable value is estimated via random sample measurement procedures. All observed (random variables) or derived statistics should be qualified through their corresponding accuracy parameters such as mean, variance, standard deviation, and covariance.

5.4.4 Resolution

Errors may be introduced as a result of using multiple databases where differences exist in any of the following: spatial resolution, spectral resolution, radiometric resolution, and temporal resolution. This issue is further described in Appendix D.

5.4.5 Timeliness Effects and Currency Errors

An attribute of a database is its currency, which informs the user of the date of its latest update or the effective date of the data. This information should be available to the user. In the absence of continuously updating databases, changes that occur between updates will not be available as part of the database until the subsequent update. In the interim, these changes may be provided to users via a Notice to Airmen (NOTAM) or other means.

For some applications, aerodrome, terrain, and obstacle databases will be integrated. This integration of data is typically accomplished by layering the various information sources into an information hierarchy that supports the application and associated display processing. The data that contribute to these layers are subject to varying levels of change, which in turn suggests that the data will be updated at different times, or in cycles of differing length. This inconsistency may result in database errors that can be difficult to detect by the system or the end user.

5.4.6 Semantic Errors

These are generally considered blunder errors. Examples include errors due to the misidentification of an object (e.g., a tower for a mast, a tree for a pole, a road for a railroad); errors due to misclassification of a theme (e.g., sand for clay); and errors due to incorrect attachment of attributes (e.g., length for width). These blunder errors will affect the consistency and the reliability of the terrain and obstacle database. Consistency checks are recommended when the initial database is produced and again on each update.

5.5 System Integrity

The required system integrity is determined using Functional Hazard Assessment (FHA). This process identifies hazards and associated failure modes for the system. The assessment identifies the mitigation required to retain the required system integrity. The system design should mitigate failure modes including those associated with database errors. Typical techniques used to mitigate system failure modes are:

- Architectural techniques such as system redundancy perhaps using dissimilar implementations. In general, redundancy allows comparison of system outputs and allows detection of system failure. Use of dissimilar implementations ensures that one implementation does not have a systemic flaw/error that could adversely affect integrity.
- The addition of monitoring and built-in test equipment (BITE) functions allows detection of system failures. The effect of monitoring or using BITE is to lower the probability of undetected failures or errors.

The techniques listed above are not intended to be comprehensive.

- The intent is to highlight that terrain and obstacle databases may contain undetectable errors, and these types of errors shall be considered in the design of the system that uses a terrain and obstacle database and in the allowed operational uses of the system.

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6 CERTIFICATION GUIDELINES

The use of terrain and obstacle databases in flight related systems presents new equipment design certification considerations for manufacturers and certification authorities. The overall integrity of the database is dependent upon the safety assessment of the function. This section provides guidance to suppliers and certification authorities.

Such guidance is provided because:

- Terrain and obstacle databases involve complex technology that is rapidly evolving,
- Some future applications may require data of higher criticality than that available today,
- Many issues are not addressed by current airworthiness documents or existing guidance materials.

Adherence to the guidelines included in this section, in addition to the quality management requirements as stated in EUROCAE ED-76/RTCA DO-200A, should allow increasing reliance on terrain and obstacle data. These guidelines should only be considered as one means, but not the only means, to demonstrate the acceptability of a terrain and obstacle database.

- To satisfy certification requirements, the supplier shall provide full traceability of database generation.

There may be cases, where one or more of the earlier stages in the production of a database are not available. This section outlines some of the issues that should be taken into account. The basic principle is that more verification and validation effort will be required if less evidence is available about the early stages of the database generation.

The structure of the remainder of this section falls into three sub-sections: terrain databases, obstacle databases, and the maintenance of databases.

6.1 Terrain Database Generation Phases

In developing a terrain database there are five phases. These are listed below as:

1. Data collection
2. Mathematical transformations
3. Database assembly
4. Verification
5. Validation

6.1.1 Data Collection

The data collection phase covers the process of recording measurements and the actions performed on those measurements to create the initial data. Some examples of methods of measurement are:

- Traditional in-situ surveys (e.g., using GPS) on the ground.
- Photogrammetric – the process of extracting or collecting digital data from a stereo image.
- Cartographic – a process of sampling and interpolation from lithographic hardcopy sources such as maps.
- Radar – from either aircraft or satellite.
- Laser Altimeter – from either aircraft or satellite.
- Synthetic Aperture Radar (SAR) interferometer – from either aircraft or satellite.

Some of these methods involve the use of complex mathematical techniques to minimise systematic errors. For example, in photogrammetry, mathematical techniques are used to reduce the distortion in the recorded images.

It is important to realise that each measurement method has weaknesses, which might lead to poor or unreliable data. The purpose of this section is not to list these weaknesses but to remind suppliers and airworthiness authorities that weaknesses exist so that compensatory actions can be described and traced.

Each measurement method has its own established standards to ensure data quality. These standards should be recorded.

Validation of the data should begin with its acquisition. Meta-data should be recorded to demonstrate integrity of the database, as required.

6.1.2 Mathematical Transformations

Once the measurements have been collected, mathematical and spatial transformations may be required to generate an elevation model.

- Transformation shall be made to achieve a common reference system.

The purpose of the mathematical transformations may be one or more of the following:

- Transformation of measurement points to the appropriate post spacing: Spatial interpolation of the measurement points may not coincide with the desired reference position. Moving the horizontal location of measurements requires interpolation of the vertical elevation data.
- Transformation of the vertical and horizontal reference systems (datum). Data sets from multiple sources such as different countries or various measurement methods may use different reference systems.

To produce a complete set of terrain data over a given area may require the combination of several databases and the identification of any gaps that remain.

- Data sets that are to be merged shall be pre-processed to have common attributes.

The data sets may contain invalid measurements that can be identified by inspections or mathematical tests. Some of these methods may allow correcting the errors. The following are principles to note:

- For each of these transformations, the supplier shall provide justification and demonstrate the validity of any assumptions that have been made. In particular, the effect of each of the transformations on the errors in the measurements needs to be understood and documented to provide a clear audit trail. Without this complete understanding the overall quality of the database cannot be determined.

Validation of the data should begin as early as possible in the data base generation processes. This can be achieved by validating data after each transformation step.

- If there is insufficient quality information available from the measurement phase or subsequent transformations, then the user of the data shall make due allowance to compensate for the missing information.

6.1.3 Database Assembly

The output of the mathematical transformation process is the set of elevations and locations that describe a region, as well as the related quality information. The next step is to organise and format the data in accordance with the requirements of the end-user. This may include filtering or systematic down-sampling the data set.

6.1.4 Verification

The data to be included in a database shall be verified at each stage of the origination/ assembly process. Verification is defined as confirmation by examination and provision of objective evidence that specified requirements have been fulfilled (ICAO Annex 15). This is necessary to ensure that the database implementation accurately represents the developer's specifications and that the database has not been corrupted in the assembly process.

The following verification techniques could be used:

- Comparison of a sample of the database points with samples from an independent measurement system. For example, for terrain databases, GPS readings at specific points can be compared to the same points in a database that was created by photogrammetric methods. For obstacle databases, this could involve re-measurement of a sample of the obstacle collection by GPS readings. The more samples that are checked, the higher the level of confidence in the quality of the database.
- Comparison of the terrain or obstacle database with other existing data sets. For this verification method, the vertical and horizontal reference datum for the data sets should be taken into account and the data sets should be independent.
- Reasonableness checks to ensure that the obstacle database does not violate known properties of obstacles, e.g., obstacles have positive heights. Reasonableness checks ensure that the terrain database does not violate known geographic extremes, such as the height of Mt Everest.
- Comparison of the database with independent measurements made during flight test.

6.1.5 Validation

It shall be demonstrated that the data requirements defined by the application manufacturer have been validated.

Validation is defined as the confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled (ICAO Annex 15/ISO 8402). The purpose of the validation process is to demonstrate that the database has sufficient overall integrity to satisfy the airborne function's requirements for certification.

It is beneficial that the database creation steps produce sufficient documentation to validate the use of the database with the airborne function. It should be demonstrated that a representative subset of the data has been validated. The size and the distribution of the subset should be considered.

The following technique represents one means, but not the only one to achieve validation:

- Demonstration by actual use of the database in simulation or flight-tests.

Note: *Other methods such as analysis applied at the beginning of the application development process could achieve these objectives.*

6.2 Obstacle Database Generation Phases

In developing an obstacle database there are five phases as listed below:

1. Data collection
2. Mathematical transformations
3. Database assembly
4. Verification
5. Validation

6.2.1 Data Collection

This phase covers the process of collecting relevant obstacle data.

The collection is usually done by the relevant State organisations but may need to be augmented from other sources.

Obstacle data that are derived from the same source material used for terrain are subject to the same considerations (§ 6.1.1).

6.2.2 Mathematical Transformations

The conversion of a set of measurements to an obstacle database can be a complex process. This is especially true since the obstacle location, extent and height measurements may have varying levels of accuracy and resolution.

Reasons for transformations on obstacle data are:

- Transformation of the reference system to align with a particular terrain database.
- Merging of several sources: to produce a complete set of obstacle data over an area may require combining several databases.

  a. Data sets that are to be merged shall be pre-processed to have common attributes.

- Identification of errors: the data sets may contain invalid measurements, which can be identified by inspections or mathematical tests. Some of these methods may allow correcting the errors.

Obstacle databases are subject to the same considerations as terrain databases mentioned at the end of § 6.1.2.

6.2.3 Database Assembly

The output of the mathematical transformation process is the set of heights, extents and locations that describe a set of obstacles, as well as the related quality information. The next step is to organise and format the data in accordance with the requirements of the end-user. This may include filtering or systematic down-sampling the data set.

6.2.4 Verification

The data to be included in a database shall be verified at each stage of the origination/ assembly process. Verification is defined as confirmation by examination and provision of objective evidence that specified requirements have been fulfilled (ICAO Annex 15/ISO 8402). This is necessary to ensure that the database implementation accurately represents the developer's specifications and that the database has not been corrupted in the assembly process.

The following verification techniques could be used:

- Comparison of a sample of the database points with samples from an independent measurement system. For example, for terrain databases, GPS readings at specific points can be compared to the same points in a database that was created by photogrammetric methods. For obstacle databases, this could involve re-measurement of a sample of the obstacle collection by GPS readings. The more samples that are checked, the higher the level of confidence in the quality of the database.
- Comparison of the terrain or obstacle database with other existing data sets. For this verification method, the vertical and horizontal reference datum for the data sets should be taken into account and the data sets should be independent.
- Reasonableness checks to ensure that the obstacle database does not violate known properties of obstacles, e.g., obstacles have positive heights. Reasonableness checks ensure that the terrain database does not violate known geographic extremes, such as the height of Mt Everest.
- Comparison of the database with independent measurements made during flight test.

6.2.5 Validation

It shall be demonstrated that the data requirements defined by the application manufacturer have been validated.

Validation is defined as the confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled (ICAO Annex 15). The purpose of the validation process is to demonstrate that the database has sufficient overall integrity to satisfy the airborne function's requirements for certification.

It is beneficial that the database creation steps produce sufficient documentation to validate the use of the database with the airborne function. It should be demonstrated that a representative subset of the data has been validated. The size and the distribution of the subset should be considered.

The following technique represents one means, but not the only one to achieve validation:

- Demonstration by actual use of the database in simulation or flight-tests.

Note: *Other methods such as analysis applied at the beginning of the application development process could achieve these objectives.*

6.3 Maintenance of Databases

Adherence to these procedures will ensure that the quality of the database is kept at an acceptable level.

- Terrain and obstacle databases shall be updated to account for errors that have been uncovered as well as to change appropriate data (e.g., due to construction activities or vegetation growth), so that the applications supported by the use of the databases have continued airworthiness.
- The processes to be used shall be in accordance with EUROCAE ED-76/RTCA DO-200A.

According to ICAO Annex 15, obstacle data are updated in accordance with the AIRAC cycle amendment schedule. Changes that occur within this period may be provided by NOTAM, data link, or an equivalent method. The method of informing the user of changes depends on the operational use of the data. Given that the data has been correctly published or otherwise made available by the data originator, the data integrator issues the updated database at the next AIRAC date. In addition, the integrator provides a list of changes that have occurred since the previous issuance.

There is no current ICAO specification for terrain data update cycles. Terrain databases must be updated in accordance with their intended use.

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Appendix A

GLOSSARY

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Appendix A—GLOSSARY

Accuracy *[ICAO Annex 15]*
A degree of conformance between the estimated or measured value and the true value.

> ***Note:*** *For measured positional data the accuracy is normally expressed in terms of a distance from a stated position within which there is a defined confidence of the true position falling.*

Aerodrome *[ICAO Annex 4]*
A defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft.

Aerodrome Elevation *[ICAO Annex 4]*
The elevation of the highest point of the landing area.

Aerodrome Reference Point (ARP) [*ICAO annex 14]*
The designated geographical location of an aerodrome.

Aeronautical Data *[EUROCAE ED-76/RTCA DO-200A]*
Data used for aeronautical applications such as navigation, flight planning, flight simulators, terrain awareness and other purposes, which comprises navigation data and terrain and obstacle data.

Altitude *[ICAO Annex 4]*
The vertical distance of a level, a point or an object considered as a point, measured from mean sea level (MSL).

Assemble *[ICAO Annex 15]*
A process of merging aeronautical information from multiple sources into a database and establishing a baseline for subsequent processing.

> ***Note:*** *The assemble phase includes checking the data and ensuring that detected errors and omissions are rectified.*

Bare Earth
A model which describes the surface of the earth, including bodies of water and permanent ice and snow, excluding vegetation and man-made objects.

Canopy
A model describing a bare earth model supplemented by the vegetation height.

Confidence Level
The Probability that errors in a database are within the limits specified. (These limits are usually defined as either linear or circular errors. Horizontal and vertical database errors can be expressed as linear error specifications. Circular error specifications are used only for horizontal database errors, since there are two dimensions in the horizontal plane. In the linear case, the limits are defined as the database mean value plus or minus the specified accuracy of the database, for vertical, latitude and longitude errors. In the circular case, the limit is defined as the accuracy radius.)

Cultural Features
Manmade morphological formations that include transportation systems (roads and trails; railroads and pipelines; runways; transmission lines), and other manmade structures, (buildings, houses, schools, churches, hospitals).

Culture *[ICAO Annex 4]*
All features constructed on the surface of the Earth by man, such as cities, railways, canals, etc.

Database ***[ICAO Annex 15]*** One or more files of data so structured that appropriate application may draw from the files and update them.

> ***Note:*** *This primarily refers to data stored electronically and accessed by computer rather than in files of physical records.*

Data Integrator
The part of an organisation, which takes data from one or more sources to produce a terrain or obstacle database that satisfies a particular specification.

Data Originator
The part of an organisation which performs measurements by a particular means and which then groups those measurements to represent an area of terrain or a set of obstacles.

Data Quality ***[ICAO Annex 4]***
A degree or level of confidence that the data provided meets the requirements of the data user in terms of accuracy, resolution and integrity.

Digital Elevation Model
Overall term for digital models of the topographic surface. Both DSM and DTM may be referred to as DEM.

Digital Surface Model
Digital model of the topographic surface, including vegetation and man-made structures.

Digital Terrain Model
Digital model of the topographic surface, not including vegetation and man-made structures. This model is also referred to as bare earth model.

Elevation ***[ICAO Annex 4]***
The vertical distance of a point or a level, on or affixed to the surface of the earth measured from mean sea level.

Ellipsoid Height (Geodetic Height) ***[ICAO Annex 4]***
The height related to the reference ellipsoid, measured along the ellipsoidal outer normal through the point in question.

End-User [***EUROCAE ED-76/RTCA DO-200A]***
The last user in an aeronautical data chain.

Error ***[EUROCAE ED-76/RTCA DO-200A]***
Defective or degraded data elements or lost or misplaced data elements or data elements not meeting stated quality requirements.

Format ***[EUROCAE ED-76/RTCA DO-200A]***
The process of translating, arranging, packing and compressing a selected set of data for distribution to a specific end user system.

Geoid ***[ICAO Annex 4]***
The equipotential surface in the gravity field of the Earth, which coincides with the undisturbed mean sea level (MSL) extended continuously through the continents.

> ***Note:*** *The geoid is irregular in shape because of local gravitational disturbances (wind tides, salinity, current, etc.) and the direction of gravity is perpendicular to the geoid at every point.*

Geoid undulation ***[ICAO Annex 4]***
The distance of the geoid above (positive) or below (negative) the mathematical reference ellipsoid.

> ***Note:*** *In respect to the WGS 84 defined ellipsoid, the difference between the WGS 84 ellipsoidal height and orthometric height represents WGS 84 geoid undulation.*

Global Navigation Satellite System (GNSS) ***[ICAO Doc 9524]***
The GNSS is a world wide position and time determination system, that includes one or more satellite constellations, receivers, and system integrity monitoring, augmented as necessary to support the required navigation performance for the actual phase of operation.

Height ***[ICAO Annex 4]***
The vertical distance of a level, point or an object considered as a point, measured from a specific datum**.**

Integrity (of aeronautical data) ***[ICAO Annex 15]***
A degree of assurance that an aeronautical data and its value has not been lost nor altered since the data origination or authorised amendment.

Line
A connected sequence of points.

Metadata
Data that describes data.

Obstacle
An individually identified object of limited spatial extent.

> ***Note:*** *Obstacles may be temporary or permanent, fixed or movable, an example of the latter being a ship. See also "significant obstacle" definition.*

Obstacle Assessment Surface
An imaginary surface used to identify significant obstacles.

Originate [EUROCAE ED-76/RTCA DO-200A]
The process of creating a data item or amending the value of an existing data item.

Orthometric Height ***[ICAO Annex 4]***
Height of a point related to the geoid, generally presented as an MSL elevation.

Point
The smallest unit of geometry which has no spatial extent. Points are described by two-dimensional (2D) or three-dimensional (3D) coordinates.

Polygon
A surface or area described by a closed line.

Position (geographical) ***[ICAO Annex 4]***
Set of coordinates (latitude and longitude) referenced to the mathematical reference ellipsoid which define the position of a point on the surface of the Earth.

Post spacing
The distance (angular or linear) between two adjacent elevation points.

Precision ***[ICAO Annex 15]***
The smallest difference that can be reliably distinguished by a measurement process.

> ***Note:*** *In reference to geodetic surveys, precision is a degree of refinement in performance of an operation or a degree of perfection in the instruments and methods used when making measurements.*

Quality ***[ICAO Annex 15])***
Totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs (ISO8402).

> ***Note:*** *There is no single or absolute measure of quality although statements about the quality of a process or item may be based upon physical measurement and observations. The quality of data is a measure of how well it meets the requirements of the data end user.*

Quality Assurance ***[ICAO Annex 15]***
All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfill requirements for quality (ISO 8402).

Required Navigation Performance (RNP) ***[ICAO Annex 4]***
A statement of the navigation performance necessary for operation within a defined airspace.

> ***Note:*** *Navigation performance and requirements are defined for a particular RNP type and/or application.*

Resolution ***[ICAO Annex 4]***
A number of units or digits to which a measured or calculated value is expressed and used.

Significant Obstacle
Any natural terrain feature or man-made fixed object, permanent or temporary, which has vertical significance in relation to adjacent and surrounding features and which is considered a potential hazard to the safe passage of aircraft in the type of operation for which the terrain and obstacle data are used.

> ***Note:*** *The term "significant obstacle" is used in ICAO Annex 4 solely for the purpose of specifying the objects to be included on charts. Obstacles are specified in other terms in Annex 14, Volumes I and II, for the purpose of clearing and marking.*

Situational Awareness
The perception of the elements in the environment within a volume of space and time, the comprehension of their meaning, and the projection of their status in the near future.

Specification ***[ISO 8402]***
Document, which establishes the requirements, the product or service should be compliant with.

State ***[ICAO Doc 7300]***
A term referring to an internationally recognised geographic entity which provides Aeronautical Information Service such as Brazil or the United States.

Terrain
Natural surface of the earth excluding obstacles. In practical terms, this will represent the continuous surface that exists between the bare earth and top of canopy that is represented by a set of elevations. (When the position of this surface, between the bare earth and upper canopy, is known it should be recorded as an attribute of the data).

Traceability ***[ICAO Annex 15]***
Ability to trace the history, application or location of an entity by means of recorded identifications (ISO 8402).

> ***Note:*** *It is the degree to which a system or a data product can provide a record of the changes made to that product and thereby enable an audit trail to be followed from the end user to the data originator.*

Validation ***[ICAO Annex 15]***
Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled (ISO 8402).

Verification ***[ICAO Annex 15]***
Confirmation by examination and provision of objective evidence that specified requirements have been fulfilled (ISO 8402).

> ***Note:*** *Objective evidence is information which can be proved true, based on facts obtained through observation, measurement, test or other means (ISO 8402).*

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Appendix B

ABBREVIATIONS AND ACRONYMS

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Appendix B—ABBREVIATIONS AND ACRONYMS

ACR	Avionics Computer Resource
ADS-B	Automatic Dependent Surveillance - Broadcast
AFM	Aeroplane Flight Manual
AGL	Above Ground Level
AIP	Aeronautical Information Publication
AIRAC	Aeronautical Information Regulation and Control
AIS	Aeronautical Information Service
ALAR	Approach and Landing Accident Reduction
AOC	Aerodrome Obstruction Charts
ARINC	Aeronautical Radio Inc.
ARP	Aerodrome Reference Point
A-SMGCS	Advanced – Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
BITE	Built-In Test Equipment
CAA	Civil Aviation Authority
CCD	Charge Coupled Device
CEP	Circular Error Probability
CFIT	Controlled Flight Into Terrain
CNS	Communication Navigation Surveillance
DEM	Digital Elevation Model
DOD	Department Of Defence
DOF	Digital Obstacle File
DSM	Digital Surface Model
DTM	Digital Terrain Model
ED	EUROCAE Document
EGM	Earth Gravitational Model
EUROCAE	EURopean Organisation for Civil Aviation Equipment
EUROCONTROL	European organization for safety of air navigation
FAA	Federal Aviation Administration
FHA	Functional Hazard Analysis
FMC	Forward Motion Compensation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICAO	International Civil Aviation Organisation
IERS	International Earth Reference System
IFSAR	Interferometric Synthetic Aperture Radar
ISO	International organisation for standardisation
JAA	Joint Aviation Authority
LIDAR	LIght Detection and Ranging
MASPS	Minimum Aviation System Performance Standards
MEF	Maximum Elevation Figures
MSA	Minimum Sector Altitude

MSAW	Minimum Safe Altitude Warning
MSL	Mean Sea Level
MVA	Minimum Vector Altitude
N/A	Not Applicable
NIMA	National Imagery and Mapping Agency
NM	Nautical Mile
NOTAM	NOtice To AirMen
OAS	Obstacle Assessment Surface
OROCA	Off Route Obstruction Clearance Altitude
PANS OPS	Procedures for Air Navigation Services OPerationS
RNAV	Area Navigation
RNP	Required Navigation Performance
SAE	Society of Automotive Engineers
SAR	Synthetic Aperture Radar
SARPs	Standards and Recommended Practices
SC	Special Committee
SG	Sub Group
STAR	Standard Terminal Arrival Route
SUA	Special Use of Airspace
TAWS	Terrain Awareness Alerting System
TERPS	United States Standard for Terminal Instrument Procedures
TIN	Triangular Irregular Network
TMA	Terminal Area
TSO	Technical Standard Order
UTC	Universal coordinated time
UTM	Universal Transverse Mercator
VFR	Visual Flight Rules
WG	Working Group
WGS-84	World Geodetic System 1984

Appendix C

APPLICATIONS OF TERRAIN AND OBSTACLE DATABASES

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Appendix C—APPLICATIONS OF TERRAIN AND OBSTACLE DATABASES

C.1 Introduction

There is an emerging need for the development and provision of electronic (i.e., digital) aviation databases (ADBs). These new databases are required to support the implementation of ICAO Communications, Navigation, and Surveillance (CNS), and air traffic management (ATM) systems and other systems as appropriate. This section presents insight from a flight technical standards perspective as to why these new databases are required, as well as to describe some of the emerging operational applications that can be supported by these new databases. Technical requirements for each application (in terms of accuracy, resolution, end-to-end system integrity, and other attributes) are presented in the following section of this document.

C.2 Background

C.2.1 Overview of Terrain and Obstacle Aviation Database Applications

Within the last several years, there has been a growing awareness by many within the aviation community that digital, computer-based avionics can be used to provide the flight crew with additional information to help them make better, more balanced judgements. Situational awareness is the term that best describes the ability of pilots to know what is going on in relationship to their aircraft and their external environment. The underlying philosophy is to make additional but relevant information available to pilots to assist them in their decision-making process, such as knowledge of one's location with respect to terrain or obstacle hazards. In this context, separation assurance is defined within a broad context as being separation from any hazard *external* to an aircraft including terrain and obstacles, adverse weather, and wake vortex hazards, as opposed to just proximate traffic.

While every aircraft cockpit provides some level of situational awareness, for example – pilots can just look out the windshield and see rising terrain – this is not enough! It is necessary to find ways to take the raw data received from various communications, navigation, and surveillance (CNS) data links, as well as from onboard aviation data bases (ADBs), and display it as processed *information* to the flight crew in a standardised, user-friendly, intuitively-obvious fashion. New air carrier and top-of-the-line general aviation aircraft, with their active matrix liquid-crystal flat-panel displays, are already heading in this direction. This is not yet so, however, at the lower end of the general aviation market, although there are innovations appearing there as well. Portable and installed displays will enable this functionality. In the end state, the ICAO CNS/ATM systems necessitate that all airspace users, including general aviation, have enhanced (and affordable) situational awareness information. This, along with a mature Free Flight separation assurance policy and procedures, will be pivotal as migration from existing airspace-based separation philosophy (that separates aircraft from airspace), to one that is fully trajectory-based is made.

Figure C.1 illustrates what a notional, cockpit-centred situational awareness architecture might look like that would support the ICAO CNS/ATM systems. At the heart of this architecture is an advanced data management computer system. The breakthrough needed is a means to make reliable computer systems for the cockpit that incorporate the concept of partitioned software applications, in essence, modular application-specific software that are affordable for all classes of airspace users. One such concept is the Avionics Computer Resource (ACR) for which technical standards (EUROCAE ED-96/RTCA DO-255) have been developed under the auspices of a joint RTCA and EUROCAE committee (EUROCAE WG-48/RTCA SC-182).

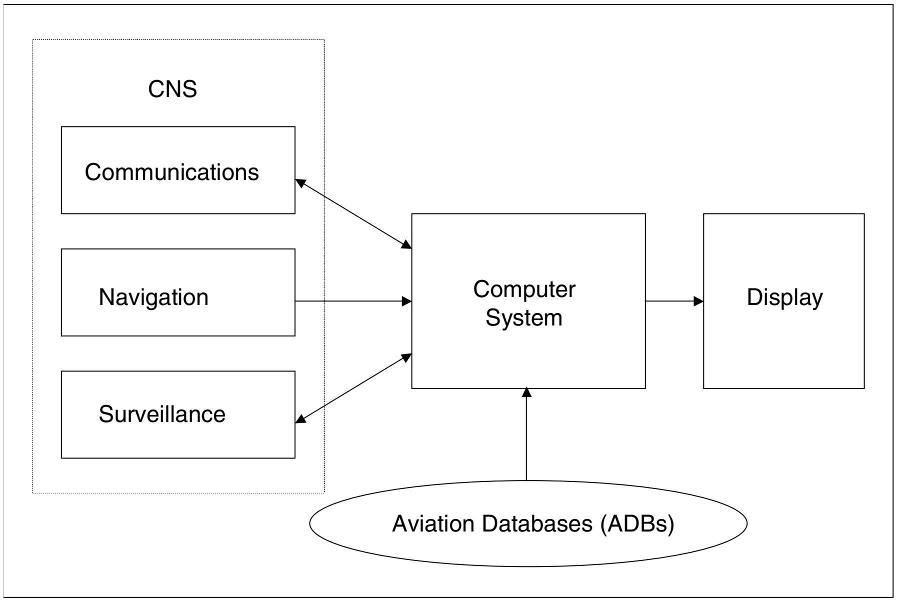

Figure C-1 Simplified Version of One Possible Advanced CNS Cockpit Architecture

To support the above notional avionics architecture, various digital aviation databases need to be developed. For example, terrain and obstacle databases can support a variety of new cockpit-based operational applications, including two-dimensional (2-D), three-dimensional (3-D), and four-dimensional (4-D) (which includes time) predictive Controlled Flight Into Terrain (CFIT) prevention systems and Approach and Landing Accident Reduction (ALAR) systems.

Additional operational applications are also possible, such as providing for an in-flight determination of "drift-down" requirements; one-engine inoperative departure climb profiles at specific airports; airport surface movement depictions for situational awareness and runway incursion protection; and development of standardised curved approach procedures. All these are examples of where these new databases, along with highly accurate airport diagram depictions, go well beyond a simple safety case.

The "core" aviation databases include navigation, terrain, obstacles, airport maps, special use airspace, and noise abatement procedures. Some of these databases (such as those for obstacles and noise) may need to be updated by Flight Information Services-Broadcast (FIS-B) data link to reflect dynamic changes to the obstacle database or changes to cumulative noise exposure levels.

Additional supportive aviation databases may also need to be developed and standardised. They include:

- communication frequency databases (including fixes for the specific air traffic sector geographic boundaries);
- traffic pattern locations and traffic pattern altitudes at uncontrolled airports;
- airspace-related databases such as air traffic minimum vectoring altitudes (MVAs), minimum sector altitudes (MSAs), off-route obstruction clearance altitudes (OROCAs), and maximum elevation figures (MEFs),
- "Clip art" of aircraft silhouettes for use in 3-D and 4-D display presentations (especially applicable for use in Automatic Dependent Surveillance-Broadcast [ADS-B] surface movement applications);

- onboard ICAO "24-bit" aircraft ID data files (to cross-index ADS-B reports with specific aircraft make and model data files);
- airspace boundary classifications for use as overlays on navigation displays, and other data (e.g., airspace for special use) to help geo-register graphical data linked Special Use Airspace (SUA) information on cockpit moving map displays).

C.2.2 Need for a Common Developmental Outline "Template"

RTCA has published "Development and Implementation Planning Guide for Automatic Dependent Surveillance Broadcast (ADS-B) Applications" (DO-249). The document identifies suggested activities that may be necessary for the development and implementation of various ADS-B applications. It is intended for use by airspace users (e.g., air carrier and general aviation operators, and the military), service providers, manufacturers, and the supporting research and development community. The material is intended to help direct development activities towards early operational implementation, but is not a replacement for any regulatory certification, operational approval, or federal acquisition process.

This planning guide provides a publicly available systematic "process" that can be used to facilitate the development and implementation of emerging ADS-B and related Communications, Navigation, and Surveillance (CNS) technologies. The guide was initially developed for ADS-B applications, however, this methodology may also be used to validate and approve other advanced CNS applications, such as those that support required navigation performance-based moving map displays, aviation databases (e.g., terrain, obstacles, and noise abatement procedures), and flight information services. The guide does not need to be followed verbatim as specific operational applications may require more or less supporting activities.

C.3 List of Selected Terrain and Obstacle Applications

C.3.1 Cockpit-Based Applications

- Terrain Awareness and Warning System (TAWS)
- Off-airway "drift-down" protection
- Emergency landing site location selection
- Synthetic vision system

C.3.2 Selected Ground-Based (or Ground Use) Applications

- Minimum Safe Altitude Warning (MSAW)
- Databases for use by the instrument procedure designer
- Air carrier engine-out procedure analysis
- Simulation / flight crew familiarisation in terminal airspace

C.4 Terrain Awareness and Warning System (TAWS)

C.4.1 Operational Concept

A digital terrain and obstacle database could support a variety of new cockpit-based Controlled Flight Into Terrain (CFIT) prevention applications, including two-dimensional (2-D), three-dimensional (3-D), and four-dimensional (4-D, which includes time) predictive controlled flight into terrain protection. There also may be a contribution to reducing approach and landing accidents that account for approximately 56 percent of the world's jet fleet accidents.

TAWS improves upon the current Ground Proximity Warning System (GPWS) technology by providing the flight crew with forward-looking information of impending dangerous terrain and obstacles. This may result in earlier alerts and more time to take any corrective action. New multifunction displays, which may become affordable for airspace users, are expected to merge terrain and obstacle databases and aircraft GNSS and flight management guidance system sensor data.

Current certified terrain warning systems (qualified under TSO C-92C/JTSO C-92C and TSO C-151A) use digitised terrain data intended for advisory use only. These databases are not presently certified for navigation as they lack sufficient certitude.

C.4.2 Benefits

CFIT and approach and landing accidents represent a significant percentage of all aviation accidents. Consequently, there is a significant safety benefit made possible by developing a comprehensive terrain and obstacle database.

C.5 Off-Airway “Drift-Down” Protection

C.5.1 Operational Concept

As aviation moves forward to use area navigation (RNAV), with point-to-point direct routings predicated on navigation systems with specified Required Navigation Performance (RNP), more aircraft will likely fly off-airways. Many of these routes will overfly mountainous terrain, or areas such as the Greenland Ice Cap. Occasional re-routings take commercial aircraft on routes where a one-engine inoperative “drift-down” (or for some other reason), may require the aircraft to descend over mountainous terrain. In some light twin-engine aircraft, one-engine inoperative cruise flight may be performance limited such that the aircraft is unable to sustain flight above the Minimum Safe Altitude (MSA). Consequently, without any outside help, pilots need to quickly and accurately calculate their best “escape” route to avoid high terrain and/or to maintain the necessary legal height separation.

C.5.2 Benefits

This operational application has both a safety as well as an operational flexibility component.

C.6 Emergency Landing Site Location Selection

C.6.1 Operational Concept

During an in-flight emergency, especially in general aviation aircraft, selection of an acceptable emergency landing site can often mean the difference between an aircraft sustaining only minor or no damage, versus sustaining catastrophic damage. The risks are great when an aircraft must land immediately for any reason when flying at night or over unfamiliar territory. Under these conditions, both the World Aeronautical Charts and the VFR Sectional Charts (both carried by VFR pilots) are of limited use in identifying potential safe landing sites, especially if the aircraft is beyond its best gliding distance from the nearest suitable airport. This situation is compounded when flying during instrument flight conditions. Under such circumstances, a high resolution, digital image, containing vegetation and cultural features, overlaid onto a terrain and obstacle database could assist pilots in identifying the safest location for a forced, emergency landing.

For example, in a composite graphical depiction, a colour rendering of the vegetation cover database could assist in an emergency landing site selection. With minor additional software feature enhancements, an aircraft’s drift-down performance, its glide path and minimum landing field requirements, could be continuously recalculated, then displayed graphically along with the vegetation / landing site image as a vector-based overlay. The effect would be to give pilots continuous information on the availability of forced landing areas. Such a software option (to the basic terrain and obstacle situational awareness database described in Section C4) would be especially helpful when flying over unfamiliar territory, at night, or during climb-out (or en route for that matter) during instrument meteorological conditions.

As additional background, the present generation of aeronautical charts does not distinguish among the various classes of foliage, or forestry land densities, as depicted in charts of rural areas. When vegetation appears on these charts, it is shown as a homogenous blanket within a well-defined boundary. Modern spectral imagery techniques can differentiate between various ground cover types. These imagery sources, however, do not reveal the relative vertical heights or densities of the composition layer.

C.6.2 Benefits

This application could produce a limited, but significant benefit to the aviation community, especially when flying at night or IMC, by expanding emergency landing options.

C.7 Synthetic Vision

The reader should note that at the time of writing this document, the requirements needed to support synthetic vision in terms of resolution, accuracy, integrity and timeliness had not been determined or validated.

C.7.1 Operational Concept

An aircraft's ability to conduct flight operations in today's airspace environment is dependent upon a number of factors. Among these, reduced visibility is a significant factor. As weather and visibility conditions deteriorate, it is increasingly difficult to conduct flight operations in the same manner and at the same rate as in visual meteorological conditions. While today's technology provides solutions to many of the problems caused by low visibility, the potential now exists to provide information well beyond what the pilot is able to see even on a clear day. The operational concept is to create a *virtual visual environment* that all but eliminates reduced visibility as a significant factor in flight operations, and enhancing what the pilot can see even in the best of visibility conditions. A virtual visual environment can be described in terms of its components and the operational flight phases it supports.

The synthetic vision "virtual visual environment" is composed of three components: an enhanced intuitive view of the flight environment, hazardous terrain and obstacle detection and display, and precision navigation guidance. The intuitive view is derived from terrain data base background images with multi-system information superimposed or integrated over them. This information is comprised of tactical information typically found on a primary flight display as well as strategic information typically found on a navigation display. Since cluttered displays are undesirable, pilots will need the ability to choose certain features so that the system and its displays will be able to present an intuitive and simple-to-comprehend visual depiction.

Required system redundancy and reliability of the synthetic vision system will be a function of the criticality of the flight operations being supported. Reversionary modes providing graceful degradation in performance along with various levels of redundancy will be needed. In addition, fail passive and fail operational capabilities will need to be an integral part of the overall system. Subsystem redundancies and cross-checking will be needed to ensure integrity of flight critical information. It is imperative that no single failure be allowed to cause a flight safety hazard. The enhanced intuitive view will also be designed to minimise nuisance alerts, the effects of spurious data, and other anomalies.

Hazardous obstacle avoidance is a prerequisite for safe flight operation in all flight phases. Consequently, synthetic vision systems will also display and appropriately highlight all terrain and obstacles that present a potential hazard to the aircraft during each phase of flight. Some possible subjects that may need to be displayed include terrain, vegetation, temporary and permanent obstacles, and "in-motion" obstructions.

Database integrity will also be a major parameter to enable the above system. Terrain and obstacle data will be of sufficient accuracy, resolution, and integrity to support precision navigation. By combining sensor and data base information, the accuracy and integrity required to support flight operations down to an instrument Category IIIb landing minima for approach (i.e., 300 feet runway visual range), may be achievable.

C.7.2 Benefits

Current technology systems allow flight crews to perform "all-visibility" en route flight operations as well as low-visibility approaches and landings to appropriately equipped runways. Synthetic vision systems will go beyond this present capability, and will further increase a pilot's situational awareness and performance by integrating existing and new procedures into a virtual visual environment. Such an expanded capability will enhance safety and provide operational benefits. All flight phases will be impacted -- ground operations, departure, en route, and arrival. Benefits derived from the individual components will be enhanced as a result of the integration of the individual technologies. Synthetic vision systems are expected to emulate day visual flight operations at night and in limited visibility conditions. Using synthetic vision systems, the overall accident rate and hull loss rate is expected to become that of day visual flight operations. Some of the expected safety benefits include a reduced risk of a controlled flight into terrain accident, airport runway incursion risk reduction, improved pilot situational awareness, improvement in unusual attitude / upset recovery, improved non-normal situation response, and improved compliance with air traffic clearances and instructions.

As attractive as the above safety enhancements might be, the economic nature of the aviation industry requires that these safety benefits be coupled with increased operational benefits so that user community support is achieved early-on in the development and implementation process. Early-on support will help ensure timely private sector participation in the development, certification, and implementation phases of this emerging technology. Consequently, several synthetic vision capacity and efficiency benefits have been identified. These benefits primarily involve enhanced airport terminal area operations. Among these are reduced arrival and departure minima, use of additional multi-runway operations, and greater airport access, among others.

C.8 Minimum Safe Altitude Warning (MSAW)

C.8.1 Operational Concept

Today, Minimum Safe Altitude Warning (MSAW) digital terrain and obstacle maps function as a last line of defence "safety net" in conjunction with terminal area airport surveillance radar. The purpose of these digital maps (and supporting software) is to alert the controller (who then alerts the pilot by voice radio) that an altitude deviation has been observed which may impose a safety of flight hazard with nearby terrain and/or obstacles. MSAW works by having ground-based radar systems monitor the flight paths of aircraft equipped with encoding transponders to ensure adequate terrain and obstacle separation. This is accomplished by comparing the flight paths with a three-dimensional grid map stored in the ground-based radar automation. When a potentially unsafe condition is detected, both a visual and an aural alarm signal alert the controller. The controller then alerts the pilot by voice radio of an unsafe condition.

An opportunity exists to expand this technology world-wide, as well as to incorporate this database alerting software with other alternative surveillance implementations such as

Automatic Dependent Surveillance-Broadcast through the development of more accurate terrain and obstacle databases.

C.8.2 Benefits

This operational application is a flight critical safety application – the "last line of defence". Air traffic relies on this data to provide flight crews with guidance pertaining to safe terrain and obstacle avoidance. For example, obstacles of record near the airport, 200 feet above ground level and higher are included in the database. However, for technical reasons, vegetation and obstacles below 200 feet above ground level (AGL) are not considered in the determination of the dominant terrain value, therefore a vegetation and uncharted obstacle correction value is added to the basic terrain value. It would appear that more accurate and more comprehensive databases of terrain and obstacles in the airport vicinity may provide increased protection against approach and landing accidents and CFIT.

C.9 Databases for Use by the Instrument Procedure Designer

C.9.1 Operational Concept

Instrument procedures include airways, standard terminal arrival routes (STAR's), departure procedures, feeder routes, and instrument approach procedures. Procedure design specialists use data describing both man-made and natural obstructions to establish minimum procedural altitudes and ground tracks based on required obstruction clearance standards. Instrument procedure specialists also evaluate various other ancillary products for air traffic to verify that required obstacle clearances are met.

C.9.2 Benefits

The minimum altitudes published in instrument procedures ensure that aircraft flown in instrument flight conditions do not impact the ground or known obstacles.

C.10 Engine-Out Procedure Analysis

C.10.1 Operational Concept

Aircraft operators are responsible for performing take-off analysis to ensure safe take-off and departures. The operational requirements for aircraft operators are set forth in ICAO Annex 6.

ICAO Annex 6, 5.2.8: "*Take-off*: The aeroplane shall be able, in the event of a critical power-unit failing at any point in the take-off, either to discontinue the take-off and stop within the accelerate-stop distance available, or to continue the take-off and clear all obstacles along the flight path by an adequate margin until the aeroplane is in a position to comply with 5.2.9."

Note: *ICAO Annex 6, 5.2.9, describes the requirements of the en-route portion of the flight.*

The Aeroplane Flight Manual (AFM) provided by the aircraft manufacturer contains the procedures and data needed to calculate the take-off weights to clear obstacles by the "adequate margin". There are many variables used in the calculations including the airport altitude and temperature, runway declared distances and obstacle location and height, to name a few. Aircraft operators are required to follow departure procedures approved by the Civil Aviation Authorities. Take-off analysis is performed to see if the departure can be flown with one engine not operating. If the weight penalties are too severe to clear obstacles vertically, the aircraft operators create an engine-out procedure. The engine out procedure deviates from the all engine departure procedure so as to allow the aircraft to clear the obstacles horizontally by turning to avoid them.

Currently, aircraft operators use ICAO Type A, B and C charts, and topographic maps to obtain the best and most accurate available obstacle and terrain data for an airport. An electronic digital terrain and obstacle database could eventually replace these products.

C.10.2 Benefits

Aircraft operators would greatly benefit by having a constantly updated, digital, standardised terrain and obstacle database. Confusion caused by different co-ordinate systems, measurement units and language translation issues may be eliminated. Aircraft operators can improve their procedure analysis, increase safety, and maximise their takeoff weights by utilising a comprehensive digital obstacle and terrain database.

C.11 Simulation/Flight Crew Familiarisation in Terminal Airspace

C.11.1 Operational Concept

This operational application would provide flight crews with a graphical “virtual reality” depiction of the geographic areas in terminal airspace. These graphical depictions could be used in ground-based simulators, including PC-based systems. Additionally, airport surface movement areas as well as ramp areas, terminal buildings, etc., could be included as graphical displays in these simulations.

C.11.2 Benefits

Flight crews could become familiar with terrain and obstacles in terminal airspace by using simulations with enhanced databases. Additionally, they can use simulators to train in order to maintain or improve proficiency.

Appendix D

TERRAIN AND OBSTACLE CONSIDERATIONS

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Appendix D—TERRAIN AND OBSTACLE CONSIDERATIONS

D.1 Reference System Considerations

In all those cases where databases already exist and are based on a different reference system, they shall be transformed to the WGS-84. In this sense the user may choose different approaches, among them the use of the *Unabridged Modelenskii Series* or the *Rigorous Solution* that is based on a seven-parameter three-dimensional transformation. This contemplates three shifts of the centre of the old to the new ellipsoid, three rotations or attitude of the old to the new ellipsoid and one scale factor relating possible local deformations of the old system.

If the user decides to apply the *Rigorous Solution* this should contemplate the local geoid undulations during the computations of the Cartesian co-ordinate system.

D.2 Errors

Modern information theory regards the observations as signals, the statistical properties of which are classified as having deterministic and stochastic components. This philosophy regards errors as properties of observations. Nevertheless, the classical theory considers errors as being of three types, namely: *Random Errors, Systematic Errors and Blunders*.

D.3 Random Errors

When talking of observational errors or random errors of observations, we refer to the basic inherent property that estimates of a random variable x do not agree, in general, with its expectation. Thus an observational error may in this context be defined as:

$v_I = x_I - \mu_x$,
with x_I= *estimate I of the random variable x*
μ_x= *population mean. (also for sample mean).*

D.4 Systematic Errors

The effects of systematic errors can be minimised via instrument calibration and/or the use of an appropriate mathematical model. From the statistical point of view it should be noted that *Systematic Errors* would affect all repeated observations in the same way. So they cannot be discovered by repetition of observations. An elimination of systematic errors can only be accomplished by the use of the appropriate mathematical model. Thus a triangle on the Earth’s surface may be treated by one of the three functional models: plane, spherical, or ellipsoidal. The choice of one over the others will result in different values of systematic errors.

D.5 Blunders

From the statistical point of view blunders, or mistakes, are observations that cannot be considered as belonging to the same sample from the distribution in question. Therefore they should not be used with other observations, and should be located and eliminated. In the advanced surveying practice statistical procedures, digital filters, etc. exist that are capable of locating and eliminating these errors.

D.6 Error Assessment

With regard to the treatment to be given to the above types of errors during terrain and obstacle data acquisition for generation purposes, statistical methods should be applied in order to assess the random errors.

Digital filters based on statistical principles should be designed in order to locate and eliminate blunders. The surveying sciences have developed highly effective techniques for this purpose. Statistical tests based on a corresponding probability density function of the measured or derived statistic, pre-adjustment data-snooping strategies, and simultaneous adjustments with robust estimators are advised for this purpose.

With regard to systematic errors, deterministic procedures should be adopted to correct the observations or they should be taken into consideration in the derived statistics. Each data acquisition method or data to be acquired has its own systematic effect or bias included in the value of the statistics themselves. To eliminate systematic errors, there are two main approaches:

1. use of the appropriate mathematical model that describes the systematic effect (e.g. Earth curvature, refraction, etc.);
2. use of extended functional models to account for a combination of systematic effects of known sources and quasi-random effects that are difficult to model. A typical case is the auto-calibration (or additional parameters) used in Photogrammetric Aero-Triangulation.

Either approach should be followed as necessary and according to the method and statistics involved.

D.7 Confidence Level of a Database

There are mainly two methods of estimation that hold four important criteria *consistent, unbiased, efficient* and *sufficient*. They are the method of Maximum Likelihood and the method of Least Squares. The Maximum Likelihood method requires knowledge of the distribution from which the observations come for the purpose of parameter estimation. On the other hand, the method of Maximum Likelihood is more laborious from the computational point of view. The majority cases deal with normally distributed observations. In this case the *Method of Least Squares* will give identical results to those of the *Method of Maximum Likelihood*.

With linear functions, the estimated parameters (in particular the estimated expectations) are consistent, unbiased, efficient, sufficient, and have the minimum variance property, especially when there are not systematic effects in the observations. Due to all above reasons, the method of Least Squares is recommended as the estimation method to use during all survey operations leading to a terrain and obstacle database.

The estimation of means, variance and covariance of random variables from sample data is referred to as *point estimation*, because it results in one value for each parameter in question. By contrast to point estimation, establishing confidence interval from sampling is referred to as *interval estimation.* After having performed point estimation – for instance, having estimated the co-ordinates of one point – the question remains:

How good is my estimation and how much can be relied on?

A simple answer is not possible because sampling never leads to the true theoretical distribution or its parameters. It is only possible to estimate probabilities with which the true value of the parameter in question is likely to be within a certain interval around the estimate. Such probability can be determined if we know the distribution function f(x) of the random variable.

$$P(x_1 < x < x_2) = \int_{x1}^{x2} f(x)dx$$

By analogy, the probability statement for a confidence interval of the parameter s, the estimate of which is $\hat{s}$ is

$$P(s_1 < s < s_2) = 1 - \alpha$$

(1 - α) is called the Confidence Level, conventionally taken to be 90%, 95%, or 99%.

The values s_1 and s_2 are the lower and the upper confidence limits for the parameter s. The above equation defines the confidence interval for the parameters as the interval around the estimate $\hat{s}$, such that the probability that this interval includes the (unknown) true value of the parameter is (1-α). The probability that the true value of the parameter does not fall in a given interval is the value α. The width of the confidence interval decreases as the degree of freedom increases and as the level of probability associated with it decreases.

Based on the above definitions we can conclude that the confidence level of a geospatial database is directly related with the lowest confidence level of existing random variables in the database.

From the statistical point of view any sort of error will affect the confidence level of the database, with a greater emphasis on the systematic and blunder errors. Methods to use to locate and eliminate these two types of errors have been outlined above.

D.8 Accuracy and Precision

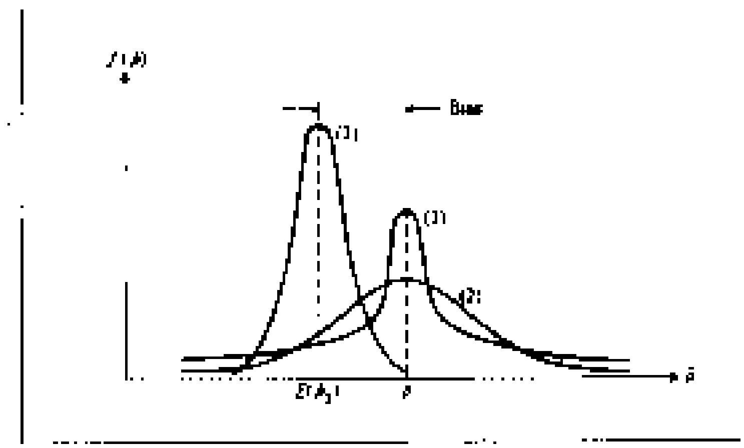

Figure D-1 Accuracy and Precision

Precision may be defined as the degree of conformity among a set of observations of the same random variable. The spread (or dispersion) of the probability distribution is an indication of the precision. Therefore in figure D.1 (2) is least precise and (3) is most precise.

Accuracy may be defined as the extent to which an estimate approaches its parameter (in conventional terms, it is considered as the degree of closeness to the "true" value). In figure D.1, both (1) and (2) are equally accurate but neither is as precise as (3). By contrast, (3) is least accurate, although is the most precise.

The main difference between precision and accuracy lies in the possible presence of bias or "systematic error". Although precision includes only random effects, accuracy comprises both random and systematic effects. Both terms are used often with the same meaning. This is because in surveying practice, in the majority of the cases, the true value is not known and only a most probable value of the population mean can be estimated via random sample measurement procedures. For the purpose of this paper both terms will have the same meaning and relate to the definition of precision. This concept is per se emphasised by the fact that geospatial data in the terrain and obstacle database should be free of systematic effects (see above definition of accuracy). Further, all observed (random variable) or derived statistics should be qualified through its corresponding accuracy parameters such as variance, standard deviation, and covariance.

A measure for accuracy proposed by Gauss is the "mean square error" (MSE) given by:

$$MSE = m^2 = E[(\hat{s} - E(\hat{s}))^2],$$

which it can be shown to reduce to:

$$MSE = m^2 = \sigma\hat{s}^2 + (bias)^2$$

D.9 Resolution

In relation with this subject, there are two possible definitions or approaches to resolution. One is according to the EUROCAE/RTCA/ICAO philosophy whose definition is in the Glossary of this document, and the second follows surveying science concepts and particularly the field of image processing. Within this context the following definitions are valid:

SPATIAL RESOLUTION is the capacity of the system (lens, sensor, emulsion, electronic components, etc.) to define the smallest possible object in the image. Historically, this has been measured as the number of line pairs per millimetre that can be resolved in a photograph of a bar chart. This is also called Analogue Resolution. For the modern photogrammetric cameras equipped with Forward Motion Compensation (FMC) devices and photogrammetric Panchromatic Black and White emulsions, this resolution can (depending on contrast) be 40 to 80 lp/mm (line pairs per millimetre). In the case of space scanner sensors mounted on satellite platforms, they record the incident radiation at a series of scan lines at approximately right angles to the flight direction of the platform. Within each scan line there is a set of recorded values called the picture elements or pixels, with each pixel being the same size as the IFOV (Instantaneous Field of View). The pixel is thus the measure of the spatial resolution limit of the scanner data.

SPECTRAL RESOLUTION is the capability of a sensor to discriminate the detected radiance in different intervals of wave lengths of the electromagnetic spectrum. Hence, the spectral resolution is determined by the number of bands that a particular sensor is capable to capture and by the corresponding spectral bandwidth. In general, a sensor will be more useful with more bands and with narrow spectral bands. The photographic systems have spectral bands covering from the panchromatic Black & White (B/W), the B/W infrared, to the natural colour or colour infrared. The electro-optic sensors typically have larger spectral resolution. For example, Spot imagery has three bands, the NOAA-AVHRR has five, and the Landsat TM has seven.

RADIOMETRIC RESOLUTION is the capability of the sensor to discriminate levels or intensity of spectral radiance. In analogue systems such as photography, the radiometric resolution is measured based on the number of grey levels that can be obtained. In opto-electronic systems, the radiance is recorded in an array of cells. A digit is assigned to each cell proportional to the received level of energy. This is done by an analogue to digital converter in the platform. Generally in the modern sensors the range is between 0 (zero) radiance into the sensor and 255 at saturation response of the detector.

TEMPORAL RESOLUTION is the rate at which a sensor can acquire a new image of the same spot of the earth's surface. This depends on the altitude of the orbit and on the aperture angle of observation.

When utilising aerial photogrammetric means to capture aerodrome data, the system resolution (i.e., combination of the optical resolution of the objective lens of the camera and resolving power of the emulsion) should be chosen based on the smallest feature that needs to be captured at the flying scale. If using satellite imagery, the selection of the bands to be used should be governed by the data elements to be captured and the size of the features to be mapped in order to derive the required spatial resolution of the imagery.

Appendix E

REMOTE SENSING TECHNOLOGIES FOR THE GENERATION OF THE TERRAIN DATABASE

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Appendix E—REMOTE SENSING TECHNOLOGIES FOR THE GENERATION OF THE TERRAIN DATABASE

E.1 Summary

The objective of this appendix is to provide basic information to the data integrator regarding remote sensing technologies for the generation of terrain databases. The main aspects outlined deal with:

- sensor types,
- characteristics of elevation models produced using stereo aerial photography, stereo pairs of satellite imagery, interferometric synthetic aperture radar and lidar,
- characteristics of existing and future data acquisition system.

Note: *When using high-altitude reflective sensing, the elevation values provided are a complex product of the sensor resolution area.*

E.2 Sensor Types

There are two types of sensors:

1. Passive (or optical) sensors, which capture the electromagnetic information, reflected on the earth surface that was originated in the sun. These include aerial photography, scanners, push-broom and CCD array types.
2. Active sensors, which illuminate the scene and capture the reflected information from the ground surface. A typical example is a radar or lidar system.

E.3 Stereo Aerial Photography

Aerial photography is instantaneous imaging of the terrain surface. As such, the electromagnetic rays which give rise to the image have the same attitude and position in space with respect to a coordinate reference system. These are the so-called exterior orientation parameters of the aerial photograph. Figure E.1 illustrates the concept. The parameters that define the position and attitude of a body in space are:

- 3 coordinates (X, Y, Z) define a position in space.
- 3 attitude angles (ϕ, ω, κ) define the attitude of the corresponding body (i.e., camera) in space with respect to a 3D coordinate reference system.

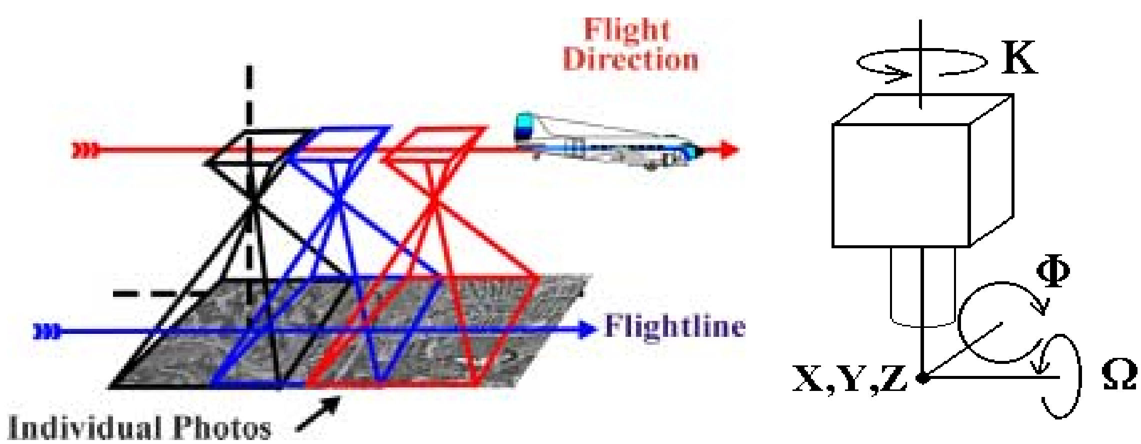

Figure E-1 Concept of Stereo Aerial Photography

Each and every point of the aerial photograph has the same exterior orientation parameters and is equal to the parameters of the photogrammetric camera at the instant of exposure.

E.4 Stereo Satellite Images

A satellite image can be thought of as an image formed by a successive integration of image lines. It consists of an array of light sensitive devices that captures the information (i.e., electromagnetic waves) coming from the ground. The captured light is converted to an electrical pulse that is transformed to a digital number and stored for transmission to a ground antenna.

Although a satellite image is exposed line by line in a continuous mode while the platform is moving in its orbit, a set of exterior orientation parameters are valid only for one line at a time.

The main geometrical difference between an aerial photograph and a satellite image lies in the fact that a satellite image does not have constant values for its exterior orientation parameters. They are approximately constant for one line (perpendicular to the instantaneous orbit direction), but vary from line to line. All points of an aerial photograph have the same exterior orientation parameters.

Aspects to be taken into consideration whenever satellite images are used for mapping purposes are the strong effects of earth curvature and atmospheric refraction.

The distortion of the satellite image caused by the earth's curvature and its variation is more significant than the effect of atmospheric refraction.

E.5 Interferometric Synthetic Aperture Radar (IFSAR)

IFSAR is a technique that uses the relative phase difference between two coherent SAR images, obtained by two antennae separated by an across-track baseline, to derive a measurement of the surface height. The baseline length is an important design parameter since the height error diverges as the length approaches zero. Conversely, if the baseline length is too large, the returns from the two antennae become de-correlated, increasing the phase measurement error. A block diagram of the basic process is illustrated in Figure E.2.

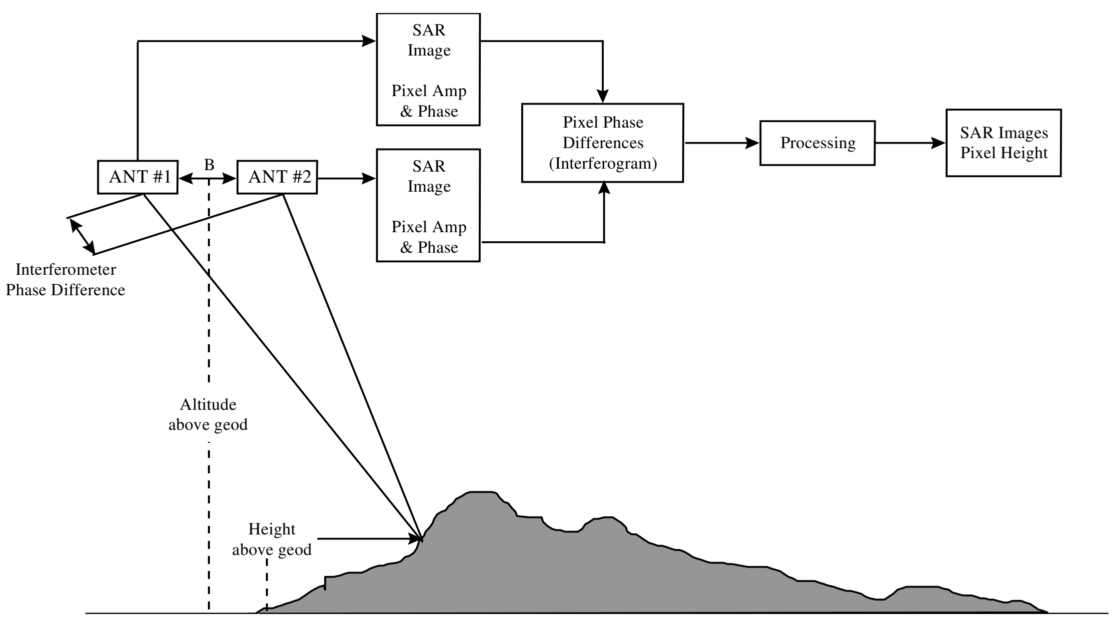

Figure E-2 Concept of Operations for IFSAR System

Highly accurate navigation information provided via tightly coupled differential GPS and inertial information drive this process. The first stage of the process is to form the image for each channel. This involves range compression, range curvature correction, and azimuth compression to form a slant plane image. An interferogram is created during the post-processing routine to extract accurate height information from the airborne data. The interferogram is created by combining the two complex SAR image data channels through a process of multiplying one channel by the conjugate of the other on a pixel-by-pixel basis.

Madsen and Zebker have developed an approach to obtain phase across the scene without the use of control points. Several references are available detailing height measurements from interferometric radar, including Graham (1974), Madsen and Zebker (1992), and Adams et al. (1993).

To solve for the height, it is critical that the position, attitude, and length of the baseline B are known to the highest possible accuracy. For this reason, the IFSAR antennae baseline must be stable. The swath width is dependent on the height above ground. As the height above ground decreases, so too does the ground coverage. The two critical parameters for the coverage are the far incidence angle and the antenna beam width.

An IFSAR system generates two main product types:

1. Digital Elevation Models: A high resolution IFSAR system produces DEMs with vertical accuracies ranging from 30 cm to 3 m, with post spacing from 5 m, and with horizontal accuracies of 1.25 m and 2.5 m.
2. Ortho-rectified Image: IFSAR high-resolution images are ortho-rectified using the simultaneously generated DEM. Consequently, the radar imagery is presented with all standard radar viewing angle height distortions removed. These images are registered to a desired projection and are mosaicked into image maps. IFSAR digital images can be used to create maps at scales as large as 1:5,000.

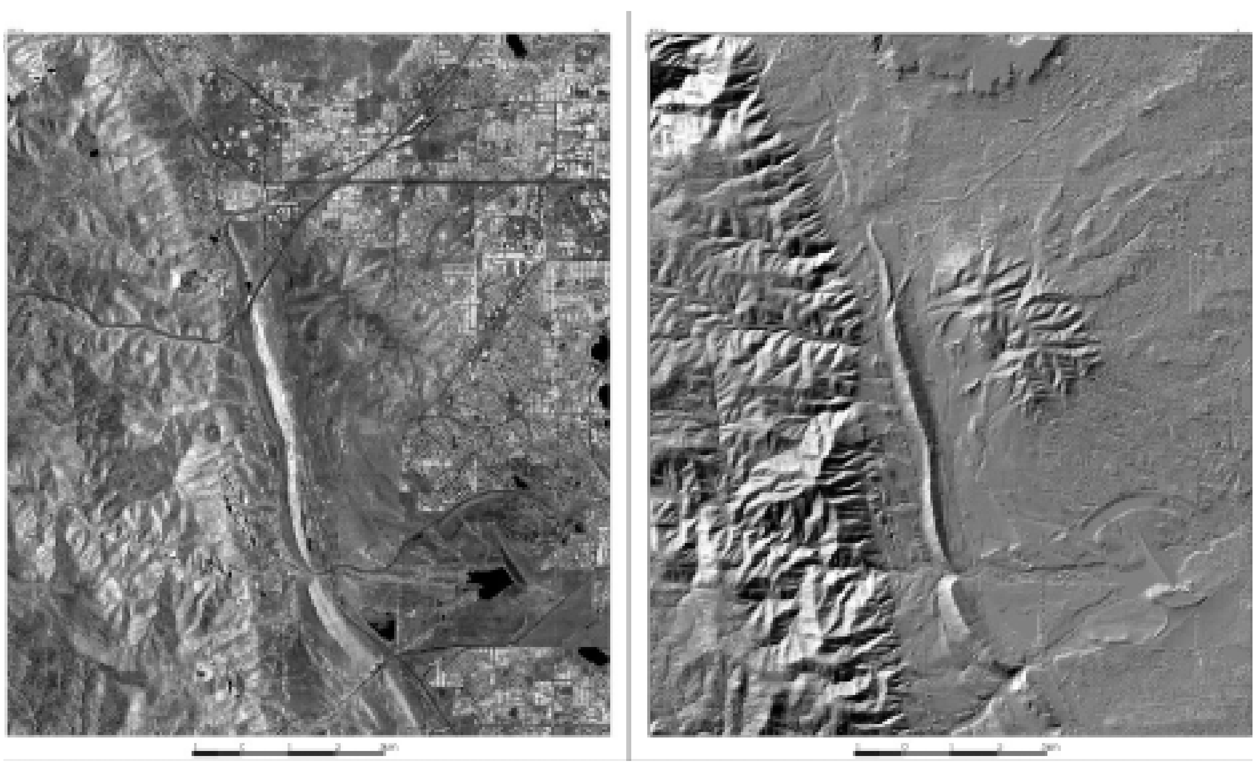

Figure E-3 IFSAR Interferometric ORI and DEM Products

E.6 Light Detection and Ranging

Airborne laser scanning systems, often referred to as LIDARs, are characterised by their transmission of pulses of optical radiation (usually near-IR) on either side of the aircraft nadir such that a zigzag or similar pattern of spots sample the terrain or objects upon it. The side-to-side geometry is usually effected by a rotating mirror or other scanning implementation. The forward motion of the aircraft then adds the second dimension. The backscattered pulses are received by the LIDAR system, and through time-of-flight measurement, the range or distance to each sample is determined. Sample separation and swath width is determined by the various operating parameters (pulse rate, scan frequency, maximum scan angle, aircraft altitude velocity, etc). Typical sample spacing may range from 50 cm to 5 meters while swath widths are normally several hundred meters. The spot diameter of the samples is usually about 0.1 – 1.0 meters diameter, also depending on altitude.

The second key component of an airborne LIDAR system is its combined GPS and Inertial Measurement Unit, which allows the range samples to be converted to (X,Y,Z) coordinates. These samples are usually an irregular set of points that can be subsequently used to create either a regularly gridded DEM or a TIN.

If the reflecting surface is the bare-ground, the elevation accuracy may be in the range 15 – 30 cm (RMSE) while the horizontal accuracy of the points is usually 1 – 3 meters (RMSE). If the reflecting surface is vegetated, some of the pulses will scatter from the vegetation, while some may penetrate through openings to the ground. The degree of vegetation penetration depends on the vegetation characteristics as well as the LIDAR system operating parameters. These factors will therefore determine how densely sampled and how accurate the resulting bare-earth DEM will be.

Appendix F

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Appendix F—REFERENCES

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Appendix G

MEMBERSHIP LIST

Appendix G—MEMBERSHIP LIST

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